The Geometry of War

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Mathematics in Arts &Architecture

Presenting :

The Geometry Of War

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Introduction

In Geometry of War, we look at four main sections namely, Gunnery, Range finding and Surveying, Fortifications and lastly Troops Formations.

In Gunnery, we traced the development of cannons through the centuries. The cannons had evolved from heavy and cumbersome ones to become much lighter and thus easier to move about. The length of the barrel of the guns will affect the firing range. We also take a look at different kinds of gunner's instruments. These instruments were very useful to gunners. Lastly, Galileo's Half Speed Rule is discussed. The Half Speed Rule is used to calculate the distance travelled by a falling object which falls at uniform acceleration from rest.

Next, range finding and surveying is mainly about the measurement of distance between two objects or stations. The two main methods are triangulation and traverse.

Then, in fortifications, we take a look at the design and shape of different forts. These two factors will affect the defence of the fort. Certain shapes such as pentagons are better than others.

Lastly, troops formations on the battlefield played an important part in determining whether an army will gain victory. There are many kinds of troops formations. In this project, only the more significant ones are discussed.

1.0 Gunnery

Any study of military weapons involves a guided tour of the 'dark side' of human nature: the ingenuity which man has never ceased to apply to the problem of killing members of his own species in the formal conflict as war or the destruction of enemy troops.

1.1 Early Canon

The Chinese have been credited with the first invention of gunpowder, but they used it primarily for peaceful purposes. Later, the Byzantines made use of the inflammable 'Greek fire' in naval warfare and the Arabs were also well aware of gunpowder. In Europe, the first definite knowledge of the formula for gunpowder is indicated in 1310, in the writings of Fiar Bacon. The first account of a European weapon that used gunpowder, was a piece of Florentine artillery, dated 1326.

By the time of the Battle of Crecy, small cannons are known to have been in service with the English arnues. These early cannons, known as bombards, were of very rudimentary construction, often being made of staves of wood or iron bound together with metal or leather hoops. Gun carriages often consisted of little more than a large piece of timber, shaped to hold the barrel. Shots were composed of iron or lead balls, but round stones were used frequently because they required less powder to fire and could be readily acquired on campaign without recourse to foundries. Early guns of this type had many limitations. As they were not cast in one piece, they lost much of their propellant force through gaps in the casing. Early cannons were also extremely cumbersome, the rate of firing was slow, accuracy was poor and accidental explosions and barrel-bursts were common. Hence, up to the fifteenth century, cannon were still overshadowed on the battlefield by the traditional weapons of medieval warfare.

In fact, the majority of medieval manuscript illustrations of cannon showed them being used in siege warfare. It was here that their relative immobility was less of a handicap and the rate of firing was less important than their effect in intimidating the defenders of fortified strongholds and their ability to hurl heavy projectiles at strong points. As a

result, a number of muzzle-loading cannon for use in static sieges were developed. 'Mons Meg', now an exhibit at Edinburgh Castle, was built in Flanders in around 1470. Weighing 5 tons and 13 feet (4m) in length, it has a bore of about 20 inches (50 cm), and could fire a stone shot of 300 lb (136 kg) in weight well over a mile. The Ottoman Turks later developed even bigger siege cannons. Under their Sultan, Mahomet the Conquer, the Turkish armies used several huge cannons to batter the walls of Constantinople.

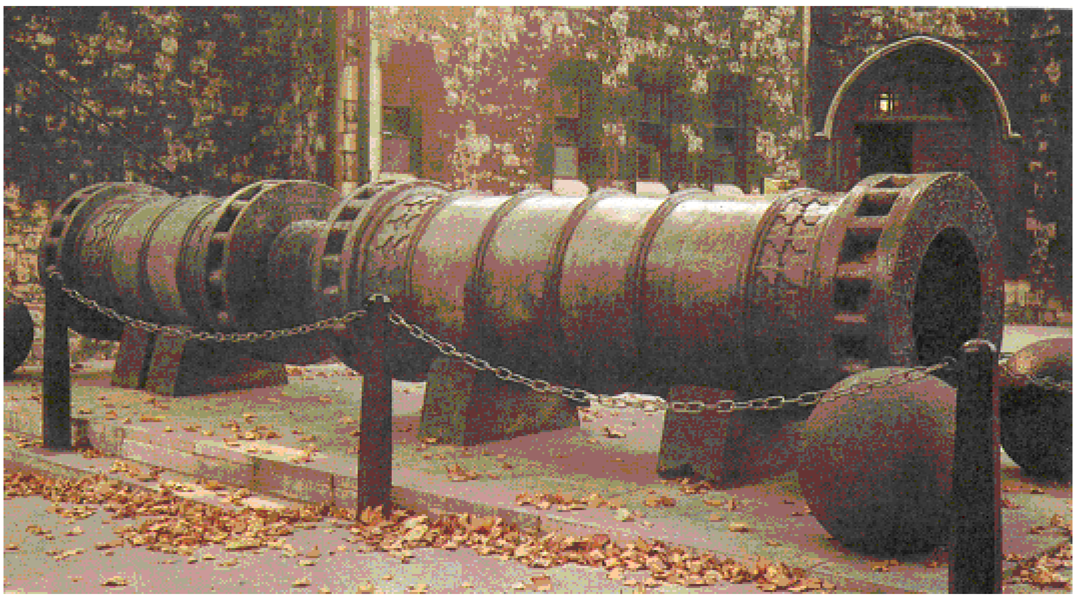


Fig 1.1.a The monster 'Dardanelles Gun' at the Tower of London illustrates the huge siege cannon of the type used to batter the walls of Constantinople by Mohammet II. Cast in two parts for ease of transport, the gun had a bore of twenty-five inches and had to be muzzle-loaded with stone or iron shot.

An example of the Ottoman siege pieces is the ' Dardanelles Gun'. It is now located at the Tower of London. It was cast in two bronze pieces for easy transport. The two pieces were screwed together to produce an artillery piece 17 feet (5m) in length, weighing over 18 tons and capable of firing a shot of 800 lb (363 kg).

1.2 The Triumph of the Gun

During the fifteenth century, the Germans came up with the technique of casting iron balls for use with cannons. These balls filled the cannon more tightly than the older stone

missiles. As a result, the expulsive force of the explosive charge was increased, giving greater range and force of impact.

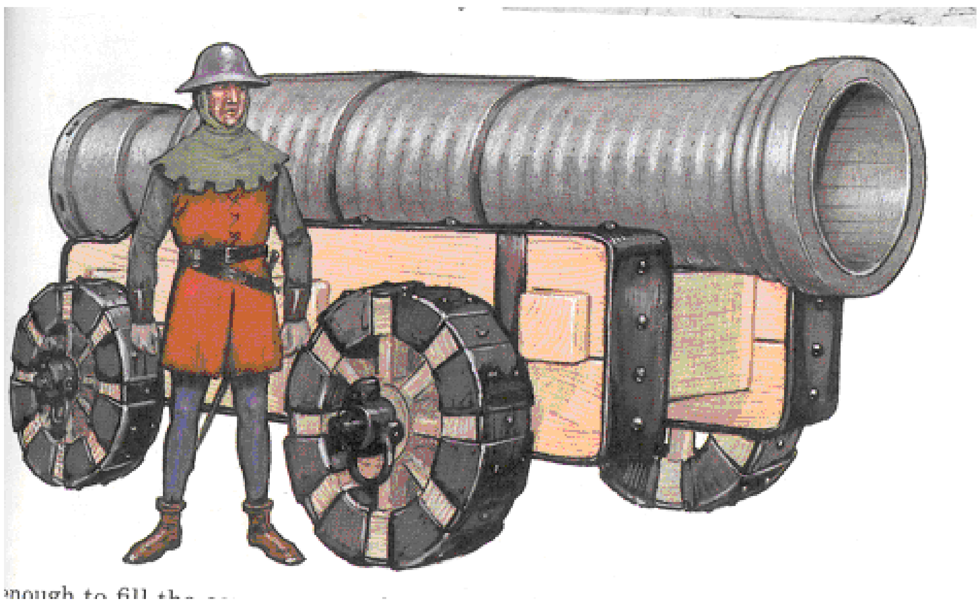


Fig 1.2.a The bombard ‘Mons Meg’

The strength of the gunpowder explosive itself was increased by the production of purer saltpeter. The greater force of the powder explosion made it necessary to increase the thickness of the gun barrel. This was not possible with the already massive bombards. Consequently, there was a movement towards cannon with thick barrel walls. A small ball (5 to 10cm in diameter) fitted the gun tightly and when fired with higher quality powder, was as destructive as a large stone ball fired from the old bombard. Such guns could be loaded via the breech, which no longer had to be narrowed significantly relative to the barrel in order to create a satisfactory expulsive force. Loading was performed by means of a crude breech block, wedged against the breech end of the barrel.

WEAPONS OF WAR

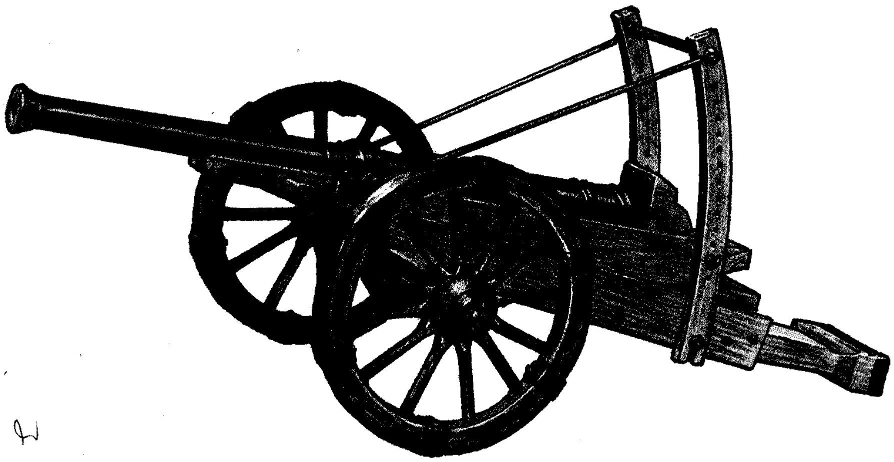


Fig 1.2.b A light fifteenth-century Burgundian cannon, known as a 'falcon', with drilled arcs at the breech to allow variable elevation.

Smaller cannons were now cast in one piece. The necessary recoil resulting from higher quality powder meant that the gun had to be set in a stronger frame. Gun frames were now built to allow a variable angle of elevation. Plugs, or trunnions, on the side of the barrel allowed it to be wedged.

During the sixteenth century, the breech-loading cannon was once again replaced by the muzzle-loaded gun. This was because it had been discovered that coarse-grained powder ignited more quickly and evenly than the commonly used fine ground powder. The coarse-grain powder produced an explosion force which the crude breech block could not accommodate. In addition, iron barrels proved too brittle to withstand the explosion. Better casting of alloys and growing expertise in boring barrels substituted the iron barrel with a more accurate and stronger smooth-bore bronze or brass one.

It was discovered that a longer barrel gave greater range. This was because more gas could accumulate in the barrel before the shot actually left it. The culverin, a gun common in the sixteenth century had an 11-feet (3.3m) barrel and can fire an 18-lb (8kg) ball across 5000 yards.

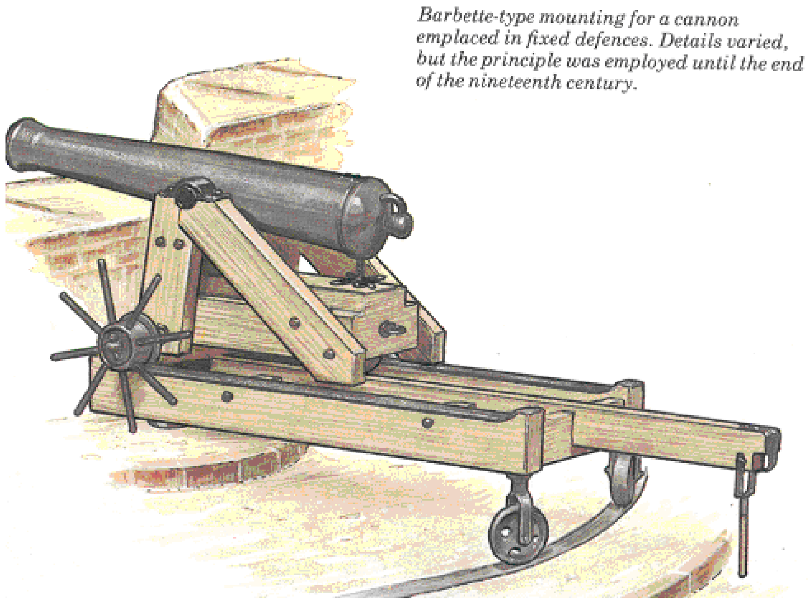


Fig 1.2.c Culverin

The growing mobility of sixteenth-century artillery was of increasing significance. Guns came to be given a two-wheeled gun-carriage for transport purpose. A large trail protruding from the carriage rested on the ground while the gun was in use. It provided a hitch for horses when the gun was being moved. The gun limber (a detachable, wheeled front to the carriage) was not yet in use, so the gun had to balance on its carriage and wheels while in transit. However, dozens of horses were needed to pull the heavy guns.

1.3 Field Artillery

By 1600, a mobile field-gun could outrange musketry. Gustavus Adolphus of Sweden was quick to realize this and sought to organize his artillery to take advantage of this. He divided it into three types namely siege, field, and regimental

.

Fig 1.3.a One of the earliest manuscript illustrates showing early handguns being used in battle. The guns are hand-culverins of a very forerunner of the arquebus

Adolphus increased the ratio of cannon to infantry by allotting two 4-pounder guns weighing 500 lb (227 kg) to each regiment and providing a 9-pounder to every thousand men. His three-man gun crews were trained to a high level of efficiency. He standardized the size of cannons by their bore diameter and the weight of their shot. To increase the rate of firing, he introduced a cartridge containing powder and shot together, and a new antipersonnel weapon, canister or case shot. It consisted of a can filled with musket balls or pieces of scrap metal which, on being fired at enemy infantry, scattered to inflict multiple casualties.

Through such measures, the Swedes emerged from the Thirty Years' War (1618-48) as the masters of the battlefield and Adolphus lodged a claim to be recognized as the father of modern warfare.

Guns were also being developed in other countries. In the sixteenth century the Dutch had begun firing bombs from a stub-barreled, large-bored siege weapon, the mortar, whose range could be increased by adjusting the angle of firing. The fuse of the bomb had to face away from the powder change, so that when the powder exploded it would

not drive the fuse into the bomb, causing it to go off prematurely. The gunner had to light the fuse and the touchhole of the mortar at the same time – a dangerous proceeding. By the end of the seventeenth century this practice had ceased, the blast of the discharge itself was sufficient to ignite the fuse even though it did not face the powder. The Dutch coehorn mortar then became widely adopted. Soon surfaced the howitzer, a short cannon, with a high angle of elevation, like the mortar and had a greater range. The howitzer, like the mortar, was also used in siege warfare.

Firing a missile designed to explode on hitting the target put a premium on accuracy. It became commonplace for gunners to attempt to control the range of a gun by manipulating its elevation. To aid in this, mathematical instruments such as the gunner's quadrant and the gunner's level were utilized and accuracy correspondingly increased. In the late 15th and 16th centuries, many mathematicians quickly responded to the development of arts and warfare by inventions of many kinds of gunneries with their deployment of navigational and surveying devices during the Renaissance. From Galileo and Newton to the humble compilers of tables, mathematicians demonstrated the value of their art by studying the fleeting path of the shot through the air.

- Galileo Galilei (an Italian Mathematician) with his half-speed rule, use of sector and his contributions to the modern day telescope.
- William Oughtred (1574-1660) was one of the world's greatest mathematicians. He invented the modern slide rule.
- Besides them, there are also many other mathematicians who greatly contributed to the development of early weapons of war as well as ingenious instruments of measurement.

We shall track the progress and evolution of the weapons of war and discuss in detail how mathematics has literally shaped the weapons of today.

1.3.1 Gunner's Sector

The **sector** was invented, essentially, simultaneously and independently by a number of different people just prior to the start of the 17th century to improve gunpowder and

advance in metallurgy. Metallurgical advances meant that stronger guns were needed to withstand more powerful explosions. However, they did not have to be heavier – in fact guns gradually became lighter. Galileo, a mathematician and astronomer, produced the most useful of the first generation of instruments and thus it is usually his name that is associated with the spread of the concept.

Fig 1.3.1.A mathematician using a sector to do a calculation

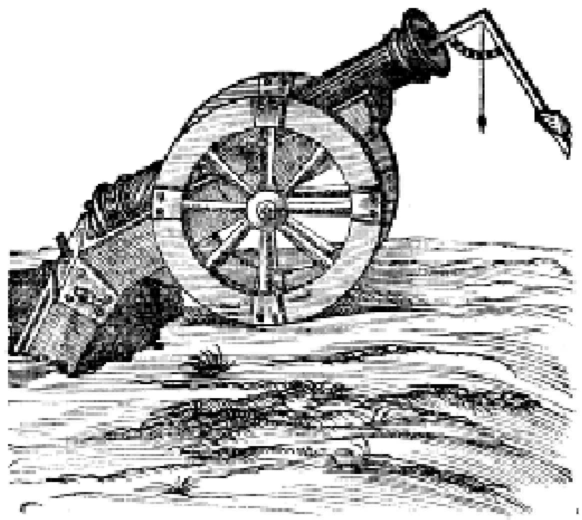


Fig 1.3.1.b
The gunner’s compass from an illustration in Tartagula’s work, 1537

The Gunner’s compass (Fig 1.3.1.b) is a modification of the sector for use with artillery. The major modifications were that two arms have been hollowed out slightly. This allowed a gunner to place a cannon ball in the space and pull it out through the points of the jaws to determine the diameter. The sector is equipped with sights for use by surveyors. It was also provided with various engraved scales for calculation and measurement. The sector also includes sectoral scales for the graphical calculation of proportions and for drawing polygons.

The furnishings on a Gunner's compass (Fig 1.3.1.b) were usually a selection of the following:

- Scale of convex diameters in inches, often marked "shot diameters"
- Scale of concave diameters in inches, often marked "bore diameter"
- Weights of iron shots of various diameters
- Weights of iron shot of various diameters
- Weights of iron shot to be used in various caliber guns
- A scale of degrees
- A table of the relations between Troy and Avoirdupois weight system
- A sector of lines, planes, solids, and polygons
- A ruler marked in inches

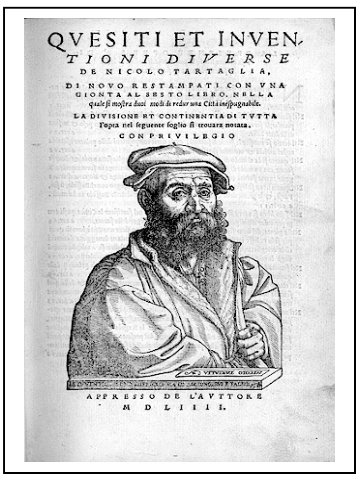


Fig 1.3.1.c La Nova Scienta

One of the works Galileo was known to have owned was La Nova Scienta by the 16th century Italian Mathematician Nicolo Tartagula. Tartagula, in investigating the 'new science of artillery, describes a gunner's quadrant used to set the elevation of cannons.

He divided the projectile's trajectory into three parts which are:

- An initial straight line propelled by the force of the gunpowder.
- A curving section as gravity began to work its effect.
- And finally a straight line again as the shot fell perpendicularly to the ground.

1.3.2 Gunner's Gauge

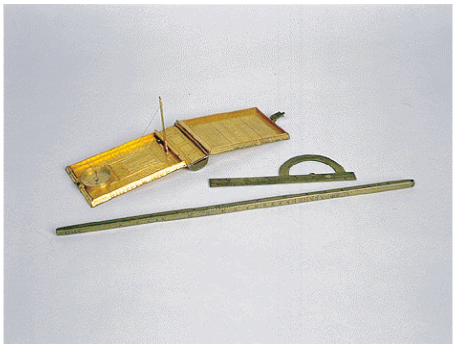


Fig 1.3.2.a Gunner's gauge

This is an instrument used to match gun to ammunition by the weight of the appropriate shot. Instead of using a balance to weigh the ball, a pair of calipers is used to measure the diameter of the shot. Then, by knowing the density and material that the ammunition is made of, a scale is charted and it can then be used to determine the weight of the shot.

Such an application of mathematics has helped to quicken the process of matching ammunition to weapons of war.

1.3.3. Gunner's Folding Rule

Signed: Benjamin Jobson 1680

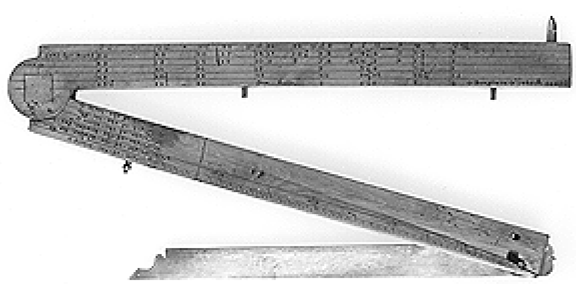


Fig 1.3.3.a Gunner's folding rule

Another handy device was the gunner's folding rule which was used to measure lengths, make calculations with dividers and to determine elevation. The rule typically incorporated artillery tables, which provided data such as the weight of shot for different artillery pieces and the amount of powder required for both ordinary use and preliminary

testing. An additional table inscribed on the rule's surface related the size of iron cannonballs (ranging from 1 to 8 inches in diameter) to their weight. In addition to the useful tables, the folding rule also carries a scale of inches, a double logarithmic line of numbers for calculation with dividers and a quadrant scale. To use the instrument as a quadrant, the thin brass arm was set at 90° to the wooden legs. With a plumb line hanging from the tip of the arm, readings are taken against the degree scale on the supporting wooden arm.

1.3.4. Folding Square

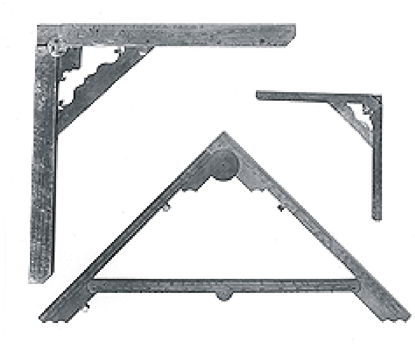


Fig 1.3.4.a Folding Square

The folding square had two principal legs with a maximum opening of 90°. When the right angle has been achieved, the hinged supporting struts locked into a straight line. For levelling, a plumb line can be attached through a hole at the centre of the main hinge. There were sectoral scales and a scale of degrees on the support, including one for polygons. The principal legs have a range of equal parts and trigonometrical scales.

1.3.5. Gunnery and Dialing Instrument

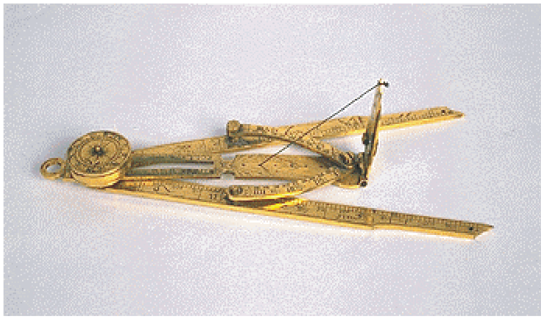


Fig 1.3.5.a Gunnery and dialing instrument

This instrument consisted of two main legs which had joint slides in the slot of a third, central leg. There are smaller link pieces connecting the side legs to the central leg. Alongside the central leg's slot are the three standard artillery scales for iron, lead and stone as well as a scale of inches. As the legs are opened or closed, the joint (which carries a compass box) moves in the slot and the edge of the compass box acts as an index to the four scales. Thus, if the points on the main legs are set to the diameter of a cannon ball, the weight of the shot can be read directly from the scales.

1.4 Galileo’s Half Speed Rule

Galileo's "half-speed rule" or "one-half speed rule" was a mathematical rule for calculating the distance fallen by an object falling with uniform acceleration from rest. The rule was geometrical in nature and involved the use of proportions or ratios. Such an application of mathematics has enabled us to apply it to the movement behaviour of a projectile. For example, when a bullet or cannon ball is fired, the rule can help to determine the projectile motion of the fired ammunition.

Here is how the half-speed rule worked.

Assume that an object accelerating from rest (zero speed) has a velocity. After three seconds of free-fall at 96 feet per second, we want to know how far this object has fallen in the three seconds. According to Galileo's rule, the distance it has fallen is equal to the distance that would be covered if the object was moving for three seconds with a *uniform,*

non-accelerating speed equal to one-half of 96, that is, with a uniform speed of 48 feet/second. So (d=½vt): the distance fallen of the accelerating object is (3 * 48 feet/second) 144 feet.

We can extend this illustration to cover other distances travelled over other times. We use a constant acceleration of 32 feet/second (meaning that during every second of elapsed time the falling object adds a speed of 32 feet/second to the speed gained through the previous second).

Step 1. Determine the distance fallen by the end of the first second.

a. What is the speed of the accelerating object at the end of one second? Since the acceleration constant is 32 feet/second, the object has accelerated to a speed of 32 feet/second in the first second of falling from rest.
b. What is one-half of 32? 16.
c. An object falling with a uniform of 16 feet/second during the entire first second (that is, always having a speed of 16 feet/second) will fall 16 feet in that second.
d. Therefore, the accelerating object will have fallen to 16 feet by the end of the first second.

Step 2. Determine the distance fallen by the end of the 2nd second.

a. What is the velocity of the accelerating object at the end of the 2nd second? During the 2nd second, the object will acquire another increment of 32 feet/second, which is added to the 32 feet/second that it had acquired during the first second. 32 + 32 = 64. Therefore, the falling object has a speed of 64 feet/second at the end of the 2nd second.
b. How far will the object have fallen by the end of the 2nd second? The distance will be equal to the distance covered by the object if it were moving at a uniform speed equal to one-half of 64, that is, at 32 feet/second for 2 seconds. A uniform speed of 32 feet/second will carry the uniformly moving object a distance of 64 feet.
c. Therefore, a uniformly accelerating object falling from rest will cover 64 feet in two seconds.

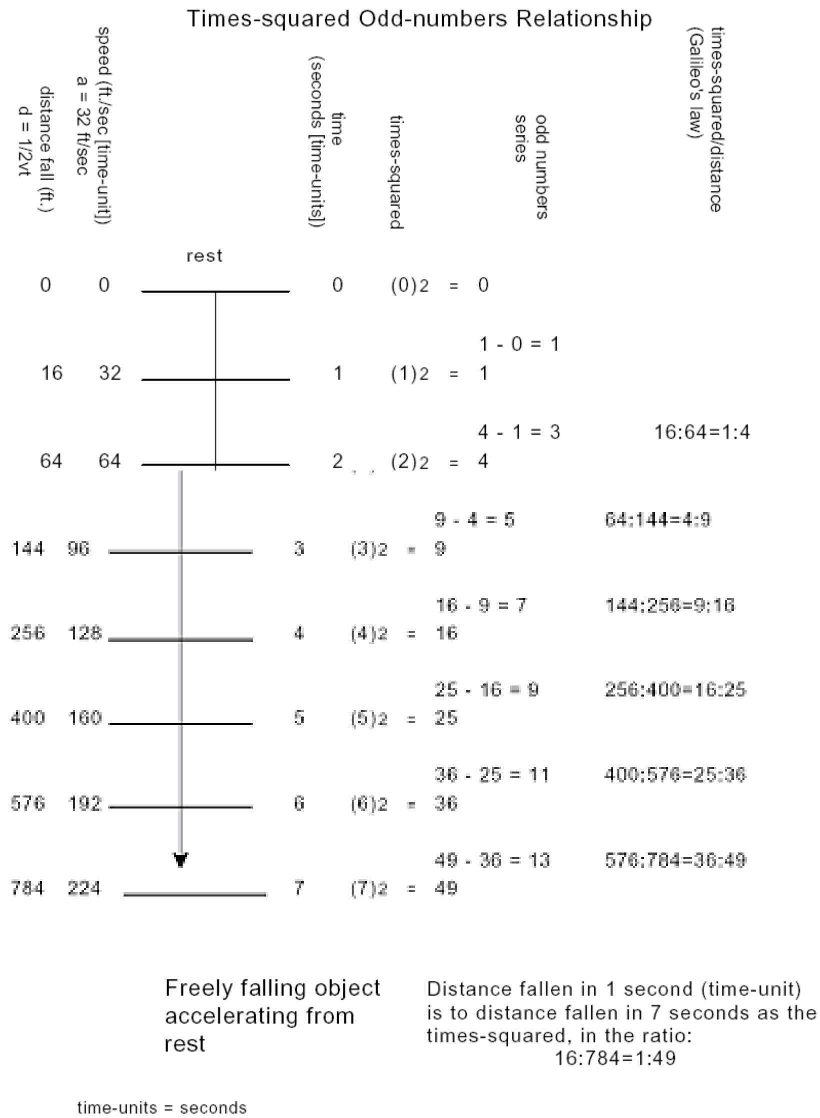
Step 3. Determine the distance fallen in three seconds.

a. What is the speed of the accelerating object at the end of the third second? During the third second, the object will add another 32 feet/second to the speed it has at the end of the 2nd second. Thus: (32 + 32) + 32 = 96. The accelerating object will be falling at a speed of 96 feet/second at the end of the third second.
b. How far will the accelerating object have fallen by the end of the third second? The distance will be equal to the distance covered by the object if it were moving at a uniform speed equal to one-half of 96, that is, at 48 feet/second, for three seconds. A uniform speed of 48 feet/second for three seconds will carry the object (48 + 48 + 48) 144 feet.

Answer: Therefore, an accelerating object will fall from rest a total distance of 144 feet in three seconds.

From these distances and times, we can derive the times-squared and odd-numbers relationships to distance fallen.

a. For the times-squared relationship, simply look at the ratios. In one second, an accelerating object has fallen to 16 feet, and in two seconds it has fallen a total of 64 feet. If we square the time, we get the ratio of 16:64 = 1:4.
b. For the odd-numbers relationship, simply subtract the times-squared from each other. For example, the first second-squared (1*1 = 1) subtracted from the second second-squared (2*2 = 4) is 3 (4 - 1).



2.0 Range finding And Surveying

In the sixteenth-century, most gunners use traditional methods of linear measurement in land surveying to determine the distance of the target. The method is as simple as to lay ropes or poles between the two stations which need to be measured. It will be a problem if one station is in a hostile position. However, the geometers of that century seek to introduce the technique of triangulation and range finding was part of their case for a new

geometry of surveying. They could locate the distant stations by sighting from the end of a measured baseline; their distances were found by measuring the angles formed with the baseline and by subsequent calculation, or by a simpler graphical method. Range finding offered a particularly appropriate application for access to the target.

There were two types of surveying instruments applied to triangulation for use in warfare. They are:

1. Triangulation instruments

   Parts of the instruments are arranged to form a triangle similar to that on the ground. For instance, by aligning rules with the lines of sight from the baseline, scaled measurements can be taken directly from graduations of the arms.

2. Instruments which employ scales

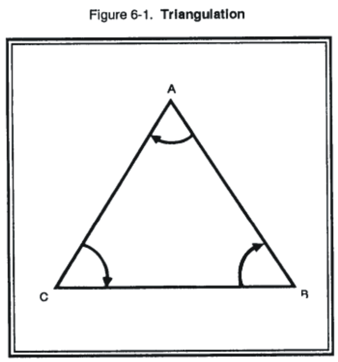
   This category is typically found on the backs of astrolabes; the circular degree scale and the shadow square or geometrical quadrant. This class includes astrolabe, theodolite, circumferentor and graphometer.

2.1 Triangulation instruments

Triangulation is a method of conventional surveying used when the traverse method cannot be implemented. This method is ideally suited to rough or mountainous terrain. The triangulation method employs oblique triangular figures and makes the surveyor able to cross obstacles and long distances. This method is time-consuming and needs careful planning and extensive reconnaissance.

The triangulation method is also used in compass mapping. There are two methods of mapping with a compass i.e. triangulation and traverse. We will cover both methods.

- ***Triangulation***



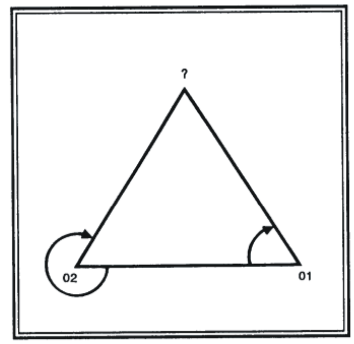


Fig 2.1.a Triangulation

Fig 2.1.b Intersection

The advantage of compass triangulation is that it allows detailed field mapping of a large area. There are two features in compass triangulation. They are intersection and resection.

1. Intersection

   This method is used to fix the positions of landmarks. In the intersection method, two angles are measured. If the length and azimuth of one side and two angles are known, we can compute the intersection. (See Fig 2.1.b)

2. Resection

   This method is to fix objects near landmarks. In resection, the coordinates of an unknown point are obtained by determining the horizontal angles at the unknown point between three unoccupied points of known coordinates. (See Fig 2.1.c)

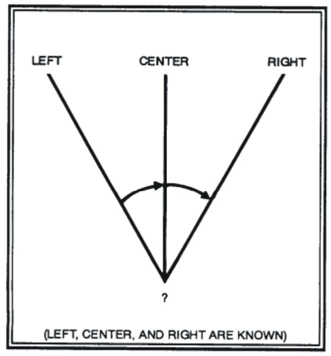


Fig 2.1.c Three-point resection

In the triangulation resection of compass, other objects and details are identified and mapped based on their bearings to the landmarks. This is similar to plane table surveying. Flat table is used to sketch bearing rays, which is similar to theodolite triangulation. Each point is part of a triangle in a triangular grid.

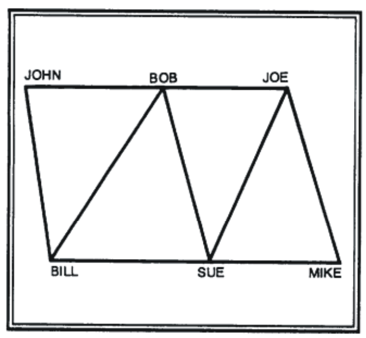


Fig 2.1.d Chain of triangle

Triangulation involves single triangles (Fig 2.1.a) and chains or schemes of triangles (Fig 2.1.d). Whether a particular triangle is a single triangle or part of a scheme of triangles, the angles in the triangle are determined in the same manner and the unknown elements of the triangle are computed in the same manner. In a single triangle, the base (a known side) is measured with electronic distance-measuring devices or a 30-meter steel tape. It can also be computed from known coordinates of the required accuracy. In a chain of triangles, the base of the first triangle is determined in the same manner as a single triangle. The base for the second triangle is the side of the first triangle that is common to both triangles. This side is computed, which establishes a base distance for computation

of the second triangle. The same procedure is used to determine the base for each triangle in a triangulation scheme.

A chain (scheme) of triangles is a series of single triangles connected by common sides. (See Fig 2.1.d) In a chain of triangles, only the length of the first or original triangle and the length of each check base are measured. The lengths of all other sides are computed.

Now we come to the compass triangulation method steps as follow :

a. Measure a base line on the ground.
   - From each end, *all landmarks* to be mapped can be seen.
   - The length should be at least 10cm long on the final map.
b. Take landmark bearings from each baseline end.
   - Use the protractor to draw bearing rays on graph paper.
   - Intersections to determine location.
     Right angles intersections are the most accurate.
   - Add new baseline and additional bearings if necessary.
     Using 3 bearings is second best accurate because it allows first and second classes point precision.
c. Objects further away makes it less accurate.

The uses of compass sketch is as follow:

1. Reconnaissance mapping prior to triangulation.
2. Sand dune distribution.
3. Tree and shrub positions.

- ***Traverse***

Traverse is used in surveying routes and lines such as the bed of a stream, route of a trail boundary of an area (polygon). After measurements, mapping is done. It is different from compass sketch.

Some terms in traverse:

- Leg → a straight line segment with distance & direction
- Chain survey → uses compass and a measuring chain

Chain survey of an area can be done as follow :

1. Mark corners of the area to be surveyed. Take bearing from the first corner (A) to the second one (B). Measure the distance from A to B using a chain or tape.

2. At point B – take a back bearing to point A. If it is 2 or 3 degrees off, we take the average of the two readings. If it is more than 3 degrees off, then redo the initial reading. Each subsequent leg is done in this way.

Several important things to note about the traverse method :

1. Make sketches of offset objects.
2. Bearings should be degree number and decimal. Do not include degree symbol as it can be easily mistaken for a 0.
3. Notes need to be clear as actual plotting is done away from location and any surveyor need to able to understand the notes.

The 2 types of traverse :

1. Closed polygons

   The main error of this type is that polygon ends do not meet.
2. Open lines

   The main error of this type is that the end of the line is not at the expected point.

2 types of traverse error :

1. Measurement of bearing as the result of :
   - Instrument error
   - External error due to local iron, magnetic north
2. Measurement of distance
   - Longer traverse results in a bigger error, but more error averaging.
   - Shorter traverse. Error due to a single distance or bearing.

Creating closure

When interior angles of a triangle are measured in the field, the sum of the angles may vary by a small amount. The term used to describe this variance is *triangle closure.*

Here are 2 ways of creating closure :

1. Spread the error among the station points.
    - This is the recommended method.
    - Station's share of error based on distance from the last point to the station
        - The first station does not change
        - Can adjust other stations' share of error
2. Adjusting a line traverse.
    - This method can only be used if the end point is clearly known.
    - Needed to determine the error of closure at the end point.
        - Same method of adjustment as area traverse.

Non-Compass traverses

Besides compass traverses, there are also non-compass traverses. Here are several non-compass traverses:

- Traversing with only a ruler. The steps are :
    1. Starts at a clearly defined landmark.
    2. Lay ruler on paper and mark direction to a landmark.
    3. Pace distance to the landmark.
    4. Use the ruler to realign the paper to the last landmark (back bearing).
    5. Draw a new line to the next landmark and pace it.
- Traversing with only a rope. The steps are :
    1. Two persons are needed.
    2. Hold the rope taut and straight between two landmarks/stations.
    3. Mark the direction on paper as with the ruler.
    4. It can be very precise.

2.2 Instruments that employ scales

- ***Theodolite***

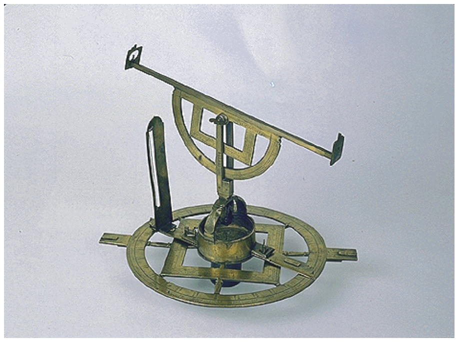


Figure 2.2.a Altazimuth Theodolite

A theodolite is a surveying instrument used for measuring horizontal and vertical angles. To measure long distances we use a system known as triangulation - we can use it, for instance, if we want to know the distance to the moon. Astronomers measure the angle of the moon above the horizon at two places on the earth's surface - as far apart as possible and at the same moment. This gives them a triangle and a base line (the distance between the two observations). Since they have measured two angles of the triangle, they know the third, because the three angles of a triangle always add up to 180. Therefore, they have enough information to find the distance between the apex (moon) and base line (earth).

The same system is used in surveying and map making, but the surveyor's base line is, of course, much shorter, in fact, both ends of the base line must be within sight of one another and of the next point to be observed. The theodolite is the basic instrument used in surveying, especially in precise triangulation.

The Theodolite can also measure :
- Elevation changes by using vertical angles (optionally, a measuring stick can be used)
- Latitude and longitude of a point by using the angles to the sun and polar stars.

There are 2 methods for determining the range using a theodolite :

- Method 1

  Determining the target range to a target not at site. This method is used when the target is expected in the target area, but has not yet arrived. With this method, the operator must move the theodolite. This lowers the precision of the range determination. Using a large baseline when possible makes up for the lower precision. The baseline recommendation is 30 meters.

- Method 2

  Determining the range to a target using the size of the target as a representative baseline. This method takes advantage of the theodolite's resolving power. A smaller target (3 to 15 meters tall or wide) can be used as compared to method 1 which uses a wide baseline of 30 meters or more.

Triangulation with a theodolite

This is the most common surveying method. As mentioned above, theodolite is a telescope mounted on a tripod. It can move horizontally and vertically. It gives readings at the minutes (or less) level. With this method, baseline is precisely measured and recorded by these few steps :

1. Theodolite placed (using plumb-line) over end of the base line.
2. Measure angle to the other end of the baseline.
3. Measure angle to other stations.
4. Move to next station.

Distances between stations are calculated from the angles and it is better to draw additional baselines to ensure overall accuracy. Finally, mapping is done back in office from field notes.

- ***Circumferentor***

Fig 2.2.c Circumferentor

Circumferentor is a surveyor's angle-measuring compass instrument. Fig 2.2.c shows a picture of a circumferentor.

You can also construct your own circumferentor. First, attach an upright piece of wood to a sturdy base. Tape a protractor to the upright, at about your eye level, then use a pin to fasten a fat drinking straw to the center of the protractor. (That is not a straw for drinking fat. It is a drinking straw that is not skinny. After all, you're going to be looking through the straw.)

To use a circumferentor, firstly see through the straw to the top of a distant object, then read the figure on the protractor at the bottom edge of the straw. Then see the bottom edge of the object and take note of the reading.

The difference between the two readings is the angular diameter of the object being observed. By observing objects of various sizes from various distances, you will discover that:

1. Objects with the same angular diameter are not always the same size.
2. The angular diameter becomes smaller as the distance increases.
3. Angular diameter depends on both the distance the real size of the object.

To determine the real size of the object, draw the angle to scale. For example, if a basketball is 10 feet away when its angular diameter is measured, draw a 10 inch line on

a sheet of paper (1 inch = 1 feet), use the circumferentor to measure to the angular diameter of the basketball (e.g., 10 degrees), and draw the angle from the 10-inch line. When the angle is extended to the same length (10 inches), an imaginary triangle is formed. The sides have the same ratio as those of the imaginary triangle formed by the viewer and the basketball.

Since 1 inch equals 1 foot according to the scale, the distance between the ends of the two lines represents the diameter of the object. If this distance is 1 and 1/2 inches, then according to this scale, the diameter of the basketball is 1 and 1/2 feet.

Astronomers have used instruments such as the circumferentor to determine that the angular diameter of the moon is half a degree. Use a protractor to draw an angle of half a degree on a long sheet of paper.

Extend the sides of the angle to represent the distance to the moon (about 240,000 miles). A scale of 1 inch to 10,000 miles will produce an angle with sides 24 inches long. When the imaginary triangle between the two sides is completed, you will find the angular diameter of the moon to be about 1/5 inch long.

From this scale, it indicates that the diameter of the moon is about 2,000 miles (the actual diameter is 2,160 miles).

- ***Graphometer***

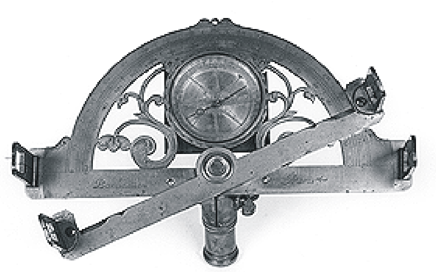


Fig 2.2.d Graphometer

Graphometer is an angle-measuring instrument. The graphometer became popular among surveyors in France and this example (see Fig 2.2.d) is from a Paris workshop of the late 18th century.

3.0 Fortifications

3.1 The design of fortifications during 1900-1940s

Fortresses built in 1914 was the continuation of a basic military concept several thousands years ago. This concept evolved through changes in artillery power, developments in military techniques and advances in building methods and materials. In Ancient Greece and Rome, the wall had been its prime expression – a principle which was also seen in the Great Wall of China. In the 12th century A.D., the Normans developed the feudal castle; walls were built higher and higher in order to resist scaling ladders. More complex crenellated designs were introduced and round corners became common in efforts to resist mining attacks. Then, the development of gunpowder and cannon in the middle ages forced walls to become lower and thicker. During the eighteenth century, there was relatively little change in the design of fortresses.

However, during the nineteenth century, design and layout changed rapidly. There were three major developments. From 1792-1852, increased mortar power meant that shells falling vertically had to be taken into consideration. Then, in the 1860s, rifled artillery appeared with enormously increased firepower and accuracy – detached forts were the result. These allowed a girdle of forts to be added to an existing fortress thus keeping enemy artillery out of range of the cities they protected. Known as “girdle” or “ring” fortresses, the diameter of the ring formed by the detached forts soon increased in proportion to the steady increase in artillery power. The third development occurred in 1885-1890: the French development of explosive shells. This replaced masonry with concrete and the use of metal cupolas to protect fortress artillery was adopted. To form

more continuous lines of defence "barrier" forts, small groups of works or single forts, were built to defend bridges, valleys, railway lines or other main lines of communication.

This very brief synopsis of fortification development indicates the striking part which considerations of artillery power had played in the evolution of fortresses during the period 1792-1914. Artillery thus dictated the basic form of fortress design at this time. Materials that were required to build the fortresses also dictated their design.

During the 1914-1 period, there was an important development in the German theory of defence: it was the aeroplane development and protection against air attacks. As a result, shelters were designed in a special way to protect against direct hits from bombs. The picture below shows the design of a shelter.

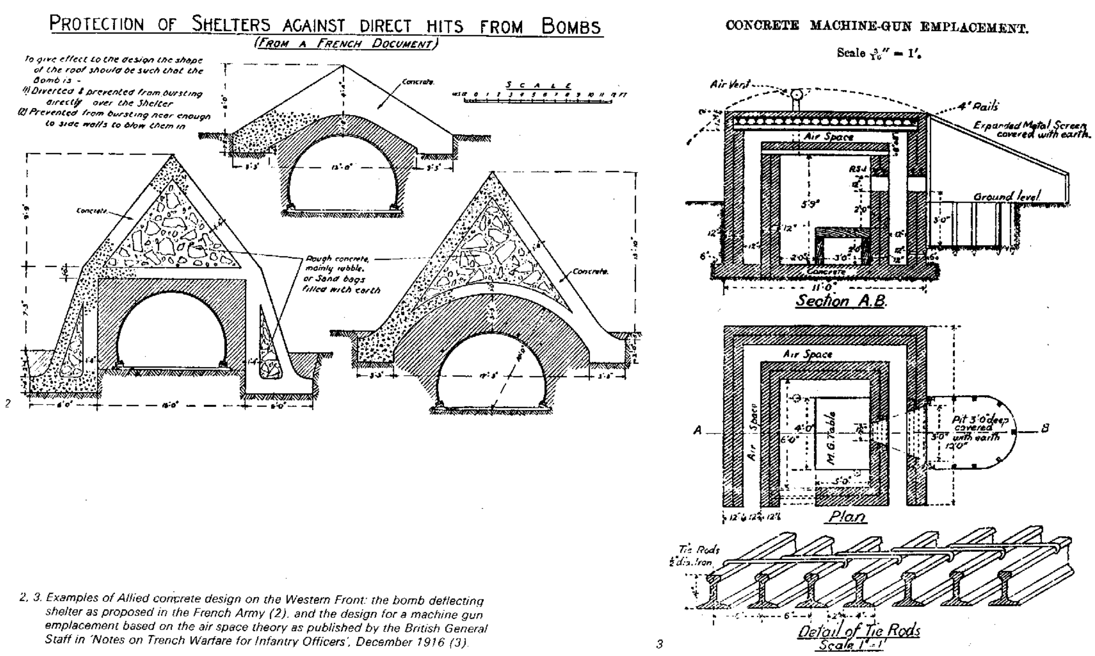


Fig 3.1.a The shape of the roof shelter

From Fig 3.1.a, the picture on the left shows that the roof of the shelter has a triangular shape so that the bomb is:

1. Diverted and prevented from bursting directly over the shelter.
2. Prevented from bursting near enough to sidewalls to blow them in.

In order to build and design a good fortification, some points should be taken into consideration:

1. Tactical sitting of the soldiers in the castle
2. Good ventilation
3. Air-tight doors were non-existent
4. Enough observation posts to observe the enemy's movement
5. The location of the fortification (whether it is on the hill or flat land)

- **Let us take a look at the British defence system in the 1900s**

Referring to Fig 3.1.b:

Reinforced concrete gun emplacements:

A. 77 mm battery
B. Mortar emplacement
C. Emplacement for a flanking field gun

Legend: *f* : firing chamber,
a : ammunition,
m : men
c : commander

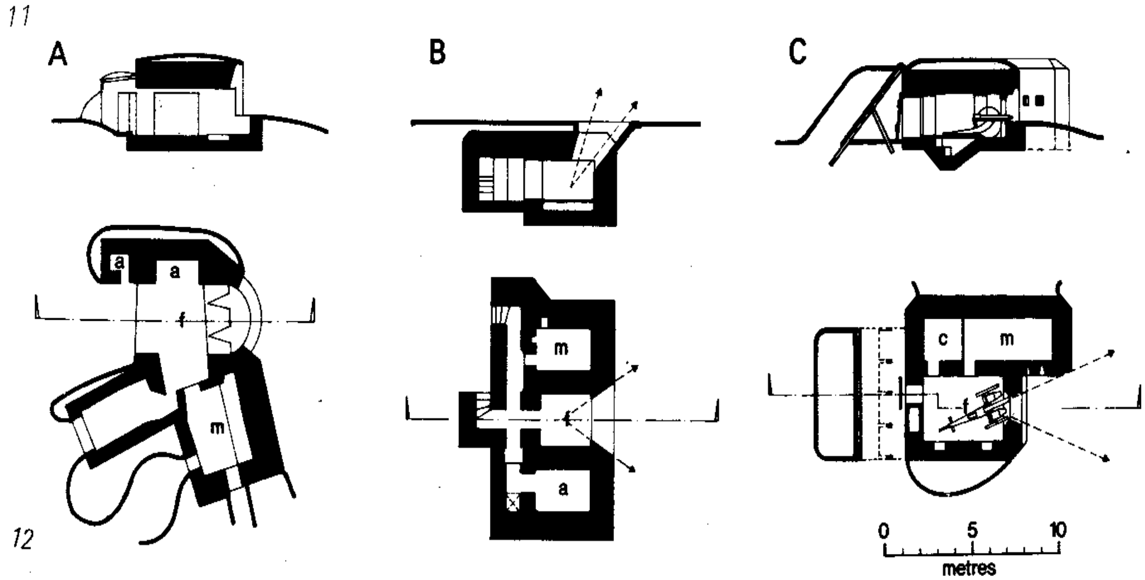


Fig 3.1.b This picture is taken from the **British defence system during 1900s**.

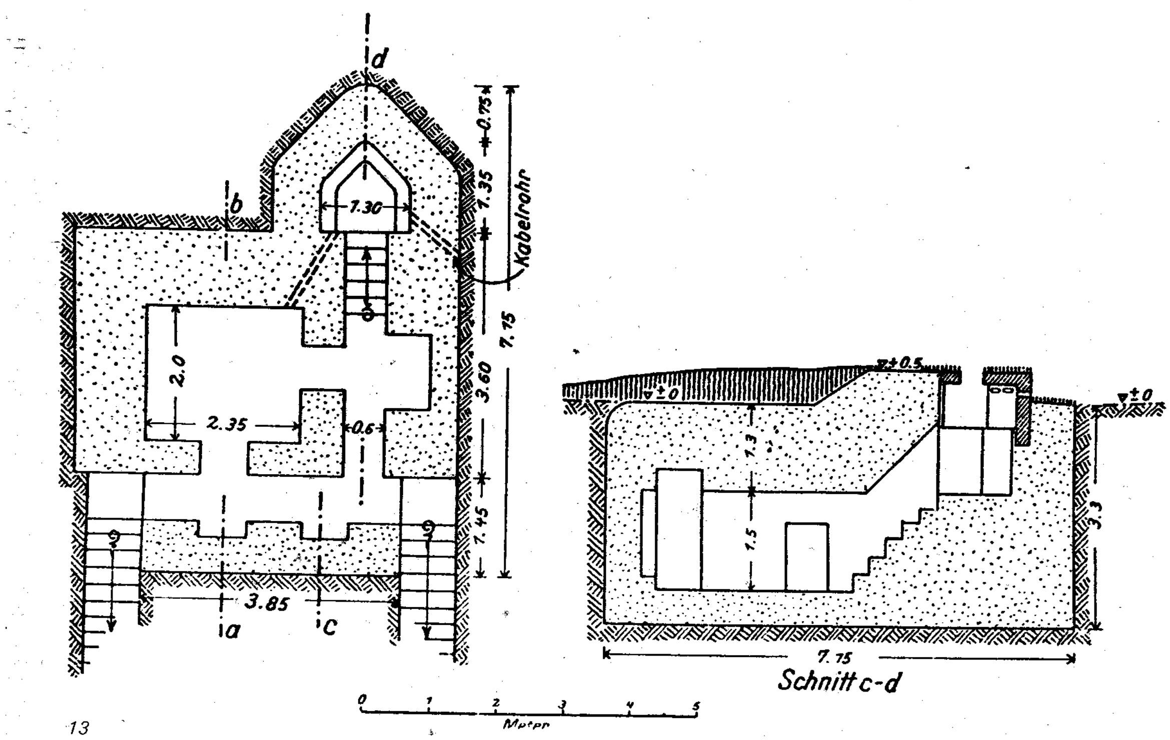


Fig 3.1.c Types of observation posts, 1916-1917

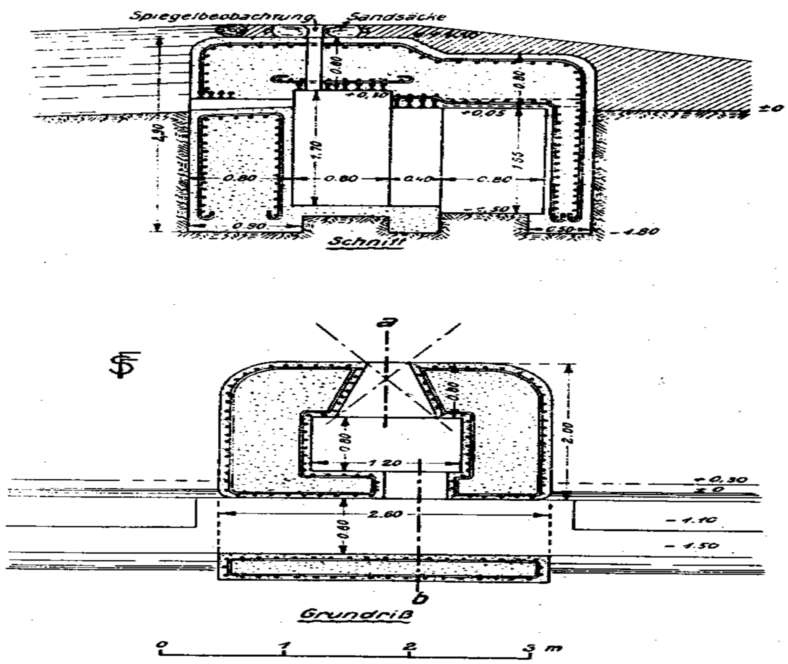


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Fig 3.1.d Front line observation post, 1916

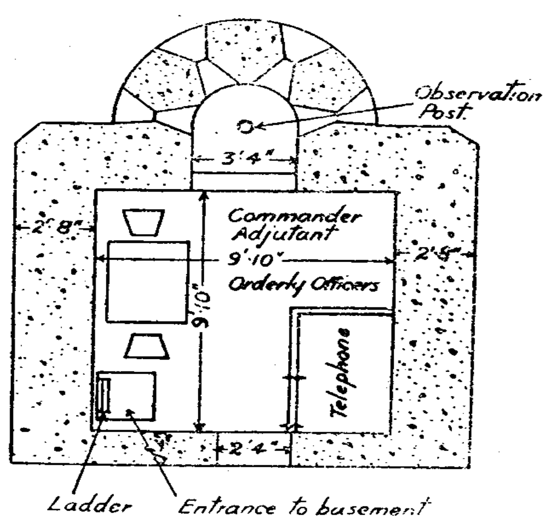

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Fig 3.1.e

- ***Command post for a Battalion or Brigade Commander: from the British translation of the Prussian manual 1916***

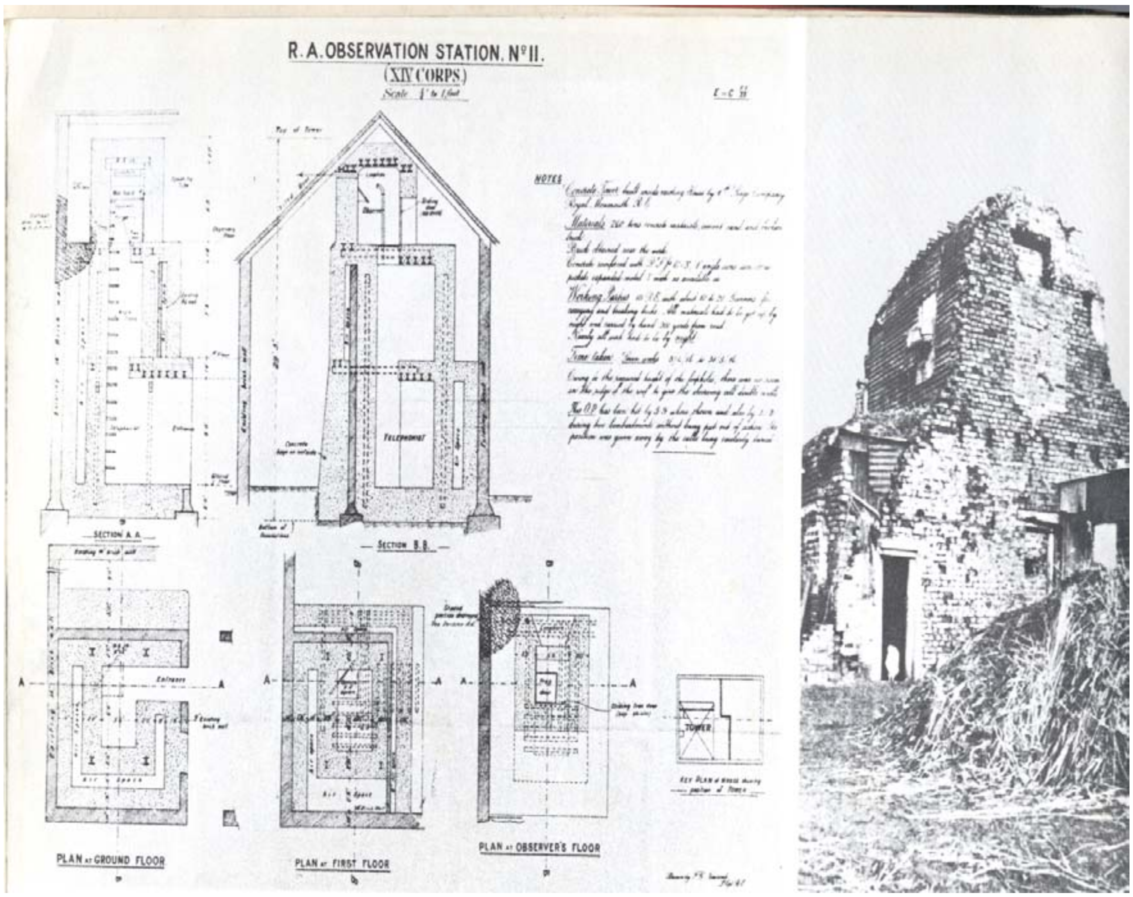


Fig 3.1.f British observation posts constructed within existing buildings in Flanders: drawing showing use of air space construction

Next, we will look at the design of the **pill box**. **Pill box** is a small shell for shooting facilitated by guns such as machine guns and can fit 2 men in the inside.

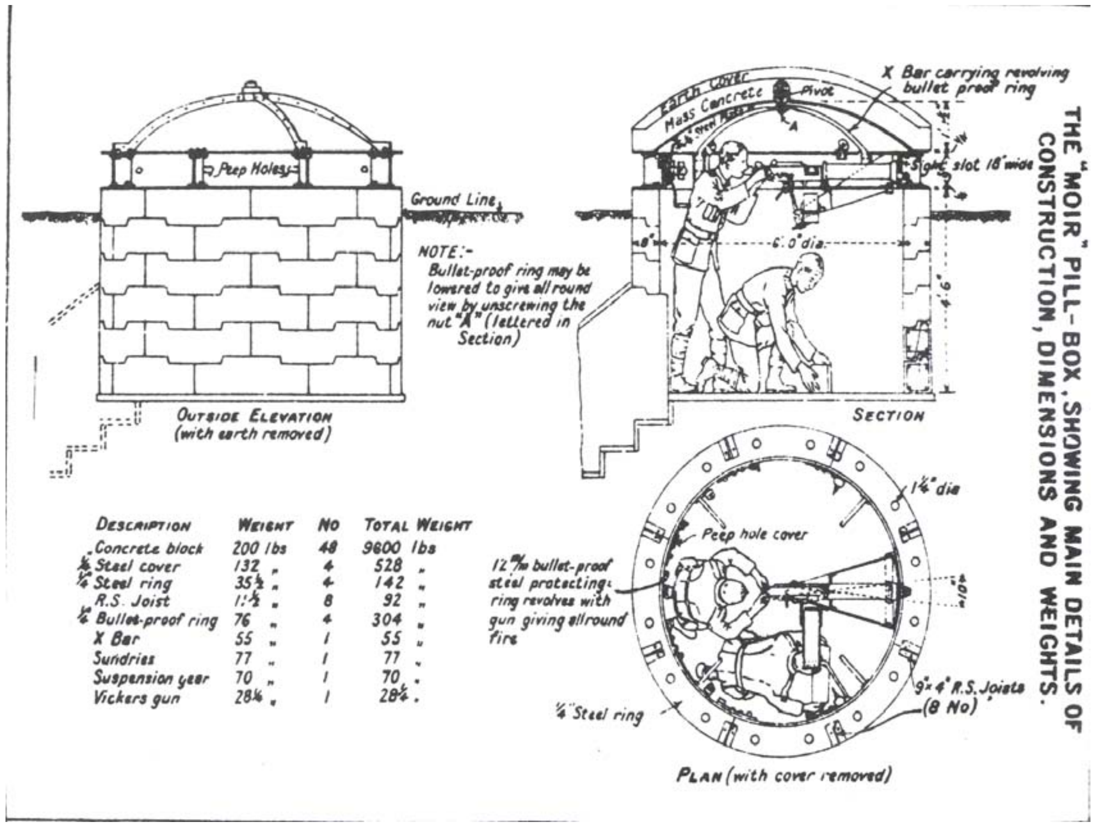


Fig 3.1.g The British 'Moir' pill box: a design based on the use of interlocking concrete blocks.

- ***The complete design and construction of French Defence***

How about the underground defence system? We will study the French defence system briefly.

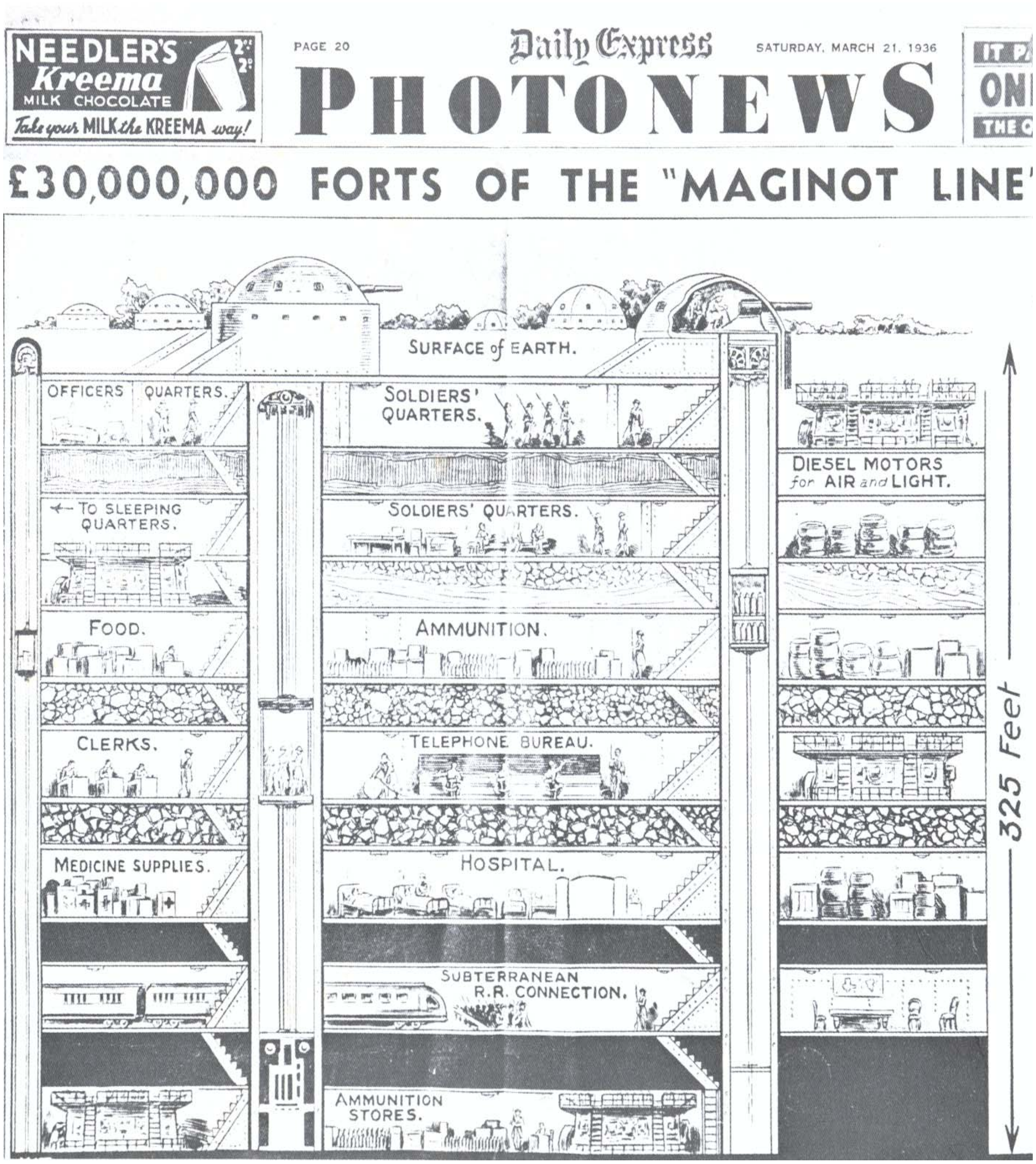


Fig 3.1.h Diagrammatic section through a Maginot Line fort as it was popularly imagined in 1936

The nerve centres of the Marginot Line were deep underground, completely out of the enemy's reach. All parts of the Marginot Line fortifications could be reached by a system of tunnels and lifts. Men and ammunitions could be moved into position without fear of enemy interference.

3.2 Forts

3.2.1 Fort Design

In the delineation of a fort that served as a royal frontier, triangles and quadrants are not to be used at all. The fort may fall out as circular as possible.

Fig 3.2.1.a Fort design

The bulwarks, which are the chief defences must be positioned where they can dominate and command over the incomings to the fort. They should be hard to approach. When it has been decided where to place a bulwark, a stake is set down. A line is then stretched between stakes. In Fig 3.2.1.a, A, B, C, D, E, F represent the stakes and the lines the breaking of the ground. The interior angles of the bulwarks should not be more than 200 paces, or 1000 feet, at five feet every pace. The reason is that the exterior angle of the bulwarks placed upon the interior angles will then stand too far away from the flanks, from which they should be defended.

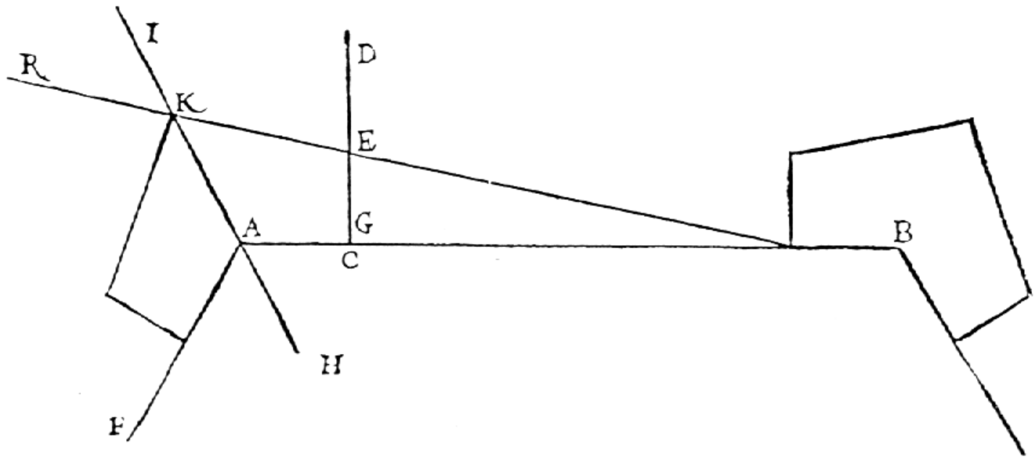


Fig 3.2.1.b Fort Circuit

In Fig 3.2.1.b, imagine that angle FAB is placed in a dirt plain. The line AB is 165 feet or 33 paces (at 5 feet every pace). AC is the length of the bulwark. In every place in the flank where artillery is used, at least 50 feet must be for the cannon. The shoulder of the bulwark should be thick because the thicker the shoulder, the longer it shall be able to resist a battle and it will also be better defended.

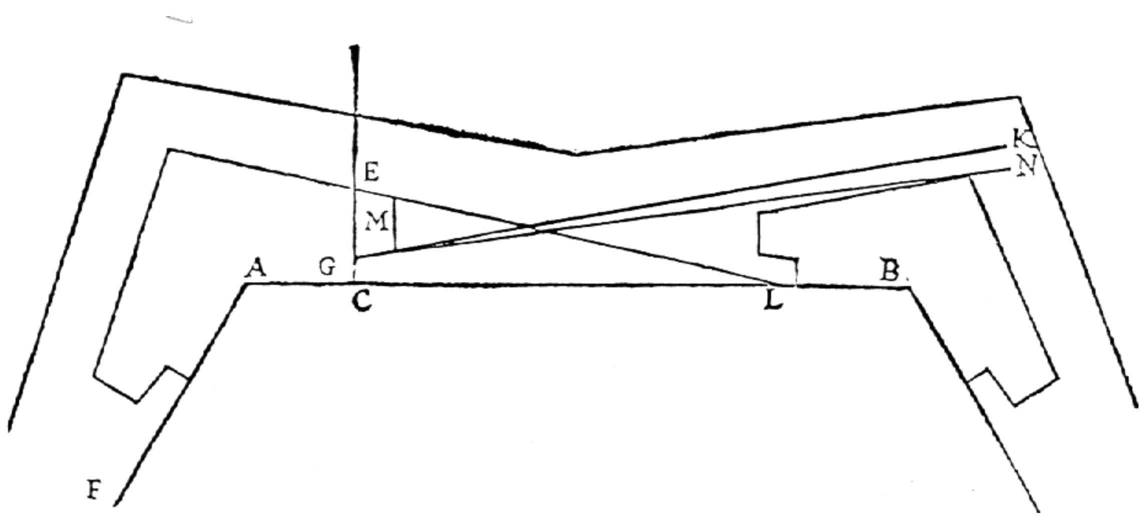


Fig 3.2.1.c Fort design

The custom is to line out the front of a bulwark precisely from the angle of the flank which defend it. To better defend the front of the bulwark, it is better to line it from the point L.(see Fig3.2.1.c) It should be placed quite a distance away from the flank but not too far also.

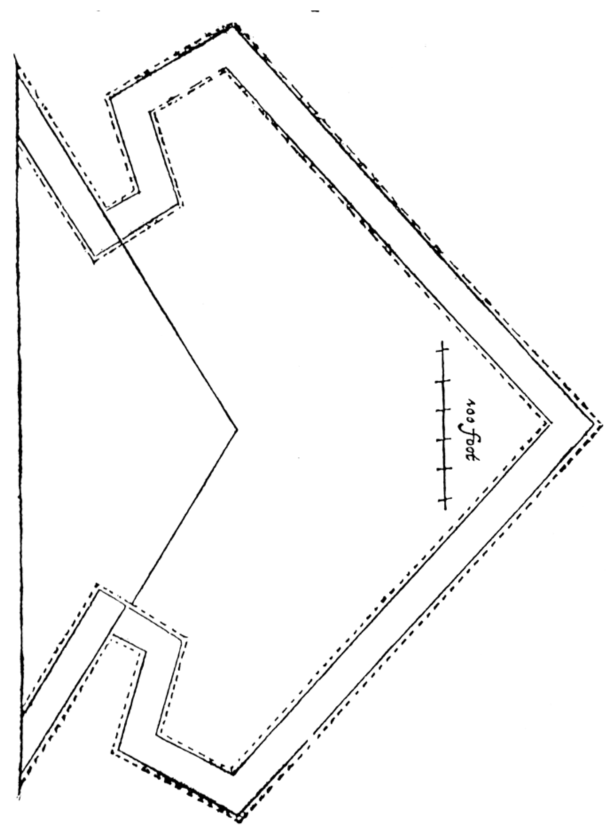


Fig 3.2.1.d Fort design

The chief strength in a fort that stands dry is the depth of the ditch. The depth of the ditch in dry ground should be 30 or 40 feet. The deeper the ditch is, the more trouble it gives an enemy in cutting the counterscarp and it also makes the assault more difficult. If the ground is water abounded, the ditch cannot be that deep. 10 or 12 feet is considered to be good enough. However, the ditch must be broad, about 100 or 120 feet. On the other hand, a ditch in dry ground only need to be 60 or 70 feet broad. Soldiers in a deeper ditch will be more protected and covered.

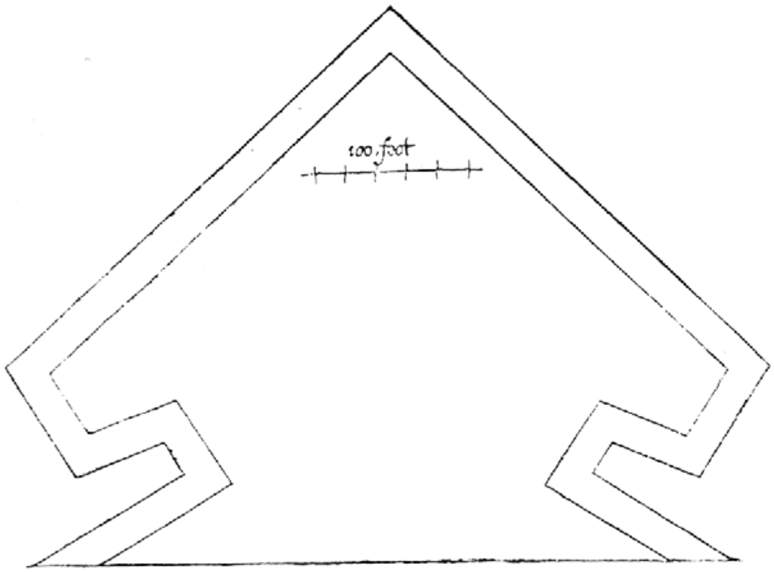


Fig 3.2.1.e Fort foundation

If the foundation of the fort is laid on fenne, marish or other such like grounds, they may not be able bear the weight of the walls. The deeper the ditch and the higher the wall is raised, the broader the foundation must be on the ground. This is to better support the weight of the walls.

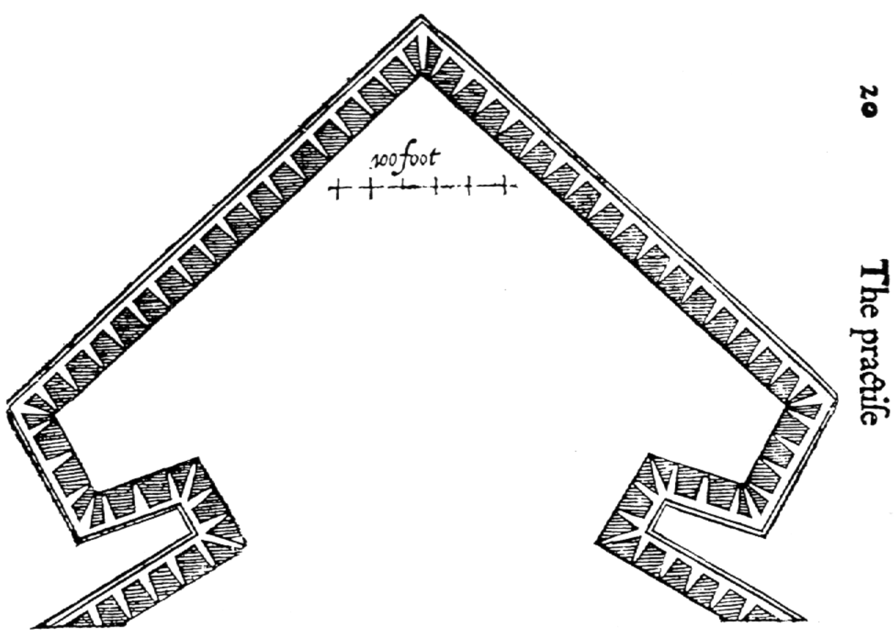


Fig 3.2.1.f Fort wall

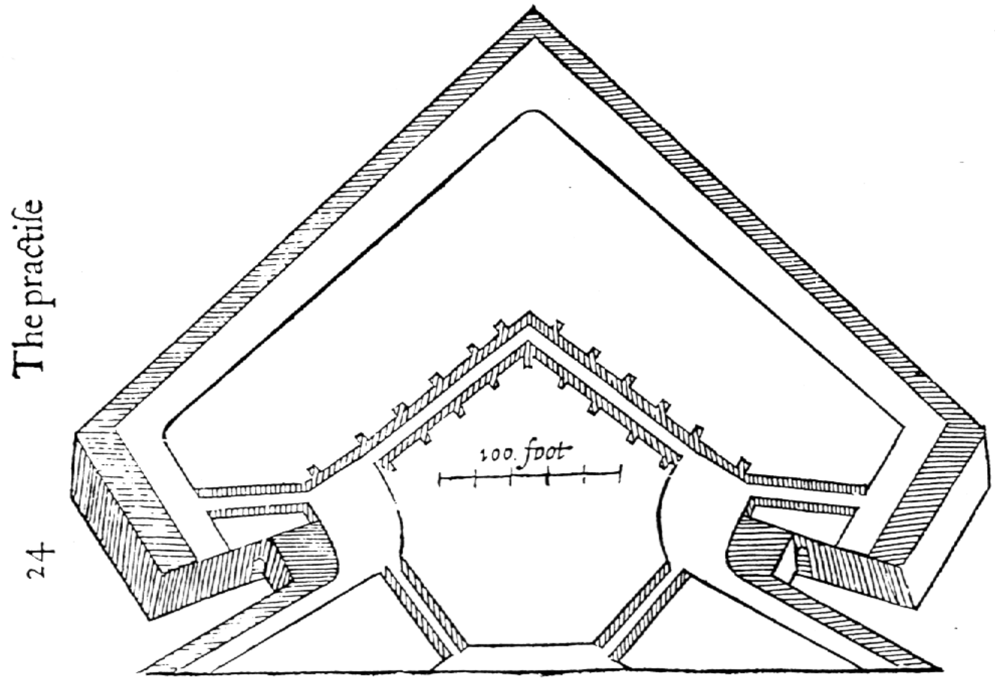


Fig 3.2.1.g Paparet

The parapet in the flank was about 25 or 30 feet thick. The gate of the fort must be placed in the middle of the Curtin so that it could be equally defended. It should also be set low to facilitate the movement of defenders so that they can move about with a lower chance of being detected.

The covered way around the fort must be ten feet broad. On dry ground, the enemy may trench and cover himself from the fort. Thus, a covered way was thought to be necessary. On low watery ground where an enemy cannot cover himself, the covered way was not a necessity.

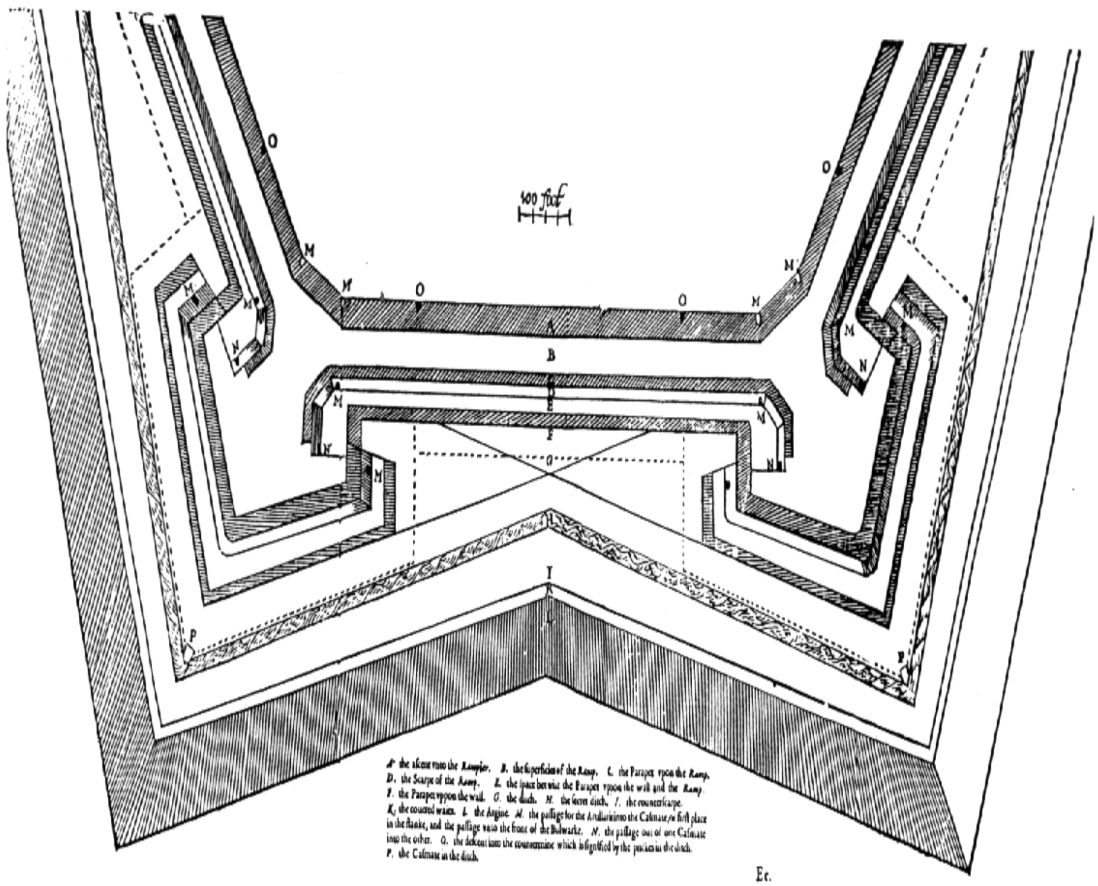


Fig 3.2.1.h Fold out diagram

A fold out diagram, with the following text:

A. The ascent unto the Romper. (*Italic*)
B. The superficies of the Ramp. (*Italic*)
C. The parapet upon the ramp. (*Italic*)
D. The Scarp of the Ramp. (*Italic*)
E. The space is twixt [sic] the Parapet upon the wall and the Ramp. (Italic)
F. The Parapet upon the wall.
G. The ditch.
H. The secret ditch.
I. The counterscarp.
J. The covered way.

K. The Argine
L. The passage for the Artillery into the Casemate, or first place in the flank, and the passage unto the front of the bulwark.
M. The passage out of one Casemate into the other.
N. The descent into the countermine that is signified by the pricks in the ditch.
O. The Casemate in the ditch.

3.2.2 Shape of forts

There is another manner of fortifying which is with earth. Instead of a face of brick or stone, a face of turf was used. This was much more durable against a forcible battle but it was not so durable against the weather. The face made of turf could be washed and moulded away by the weather. However, the face can be repaired again. Some forts contained 160 paces square, some 100, some 80 and others 60, 40 or less. The shape of forts was generally divided into 3 groups, pentagonal, rectangular and irregular.

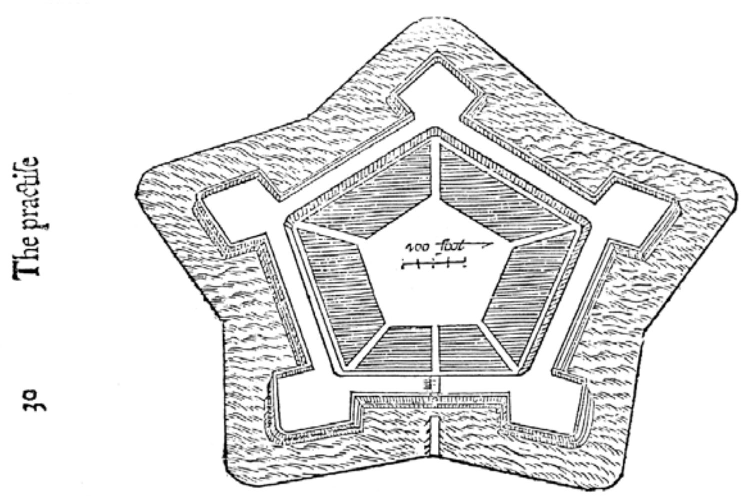


Fig 3.2.3.a Pentagonal Shape

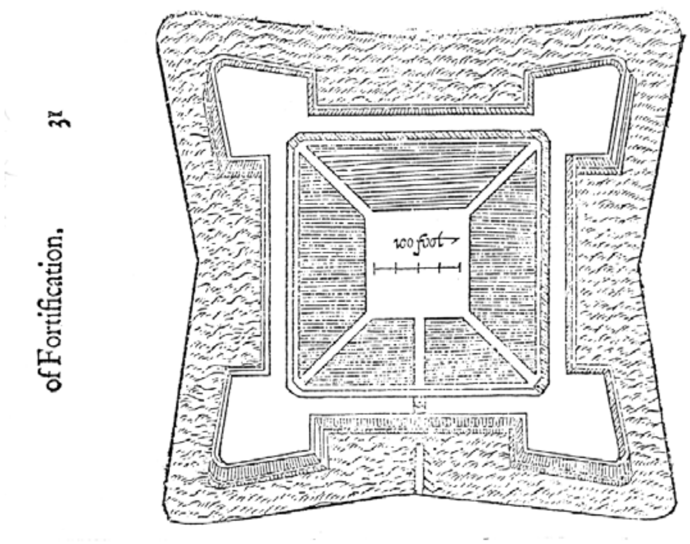


Fig 3.2.3.b Rectangular Shape

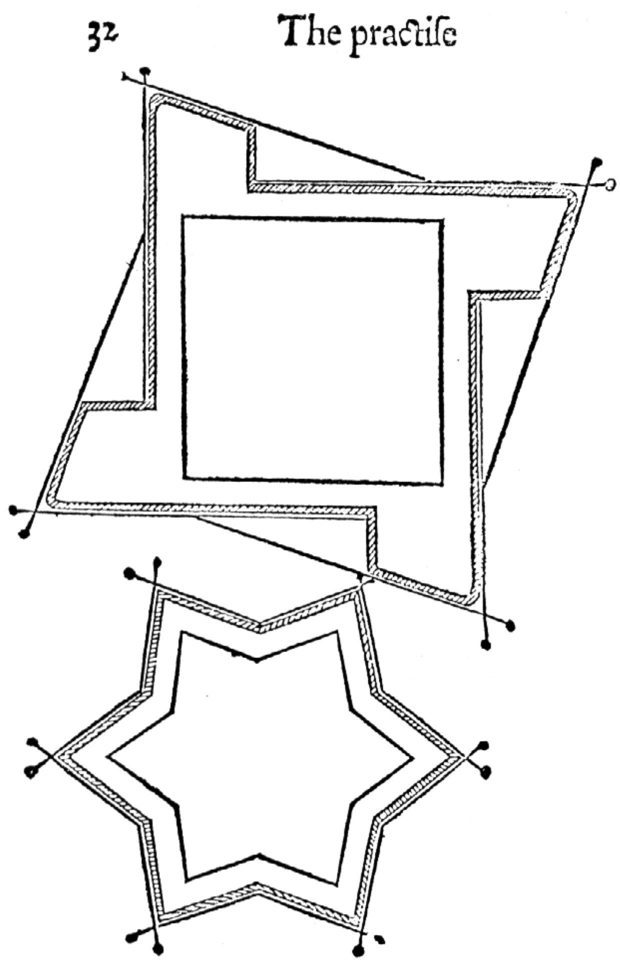
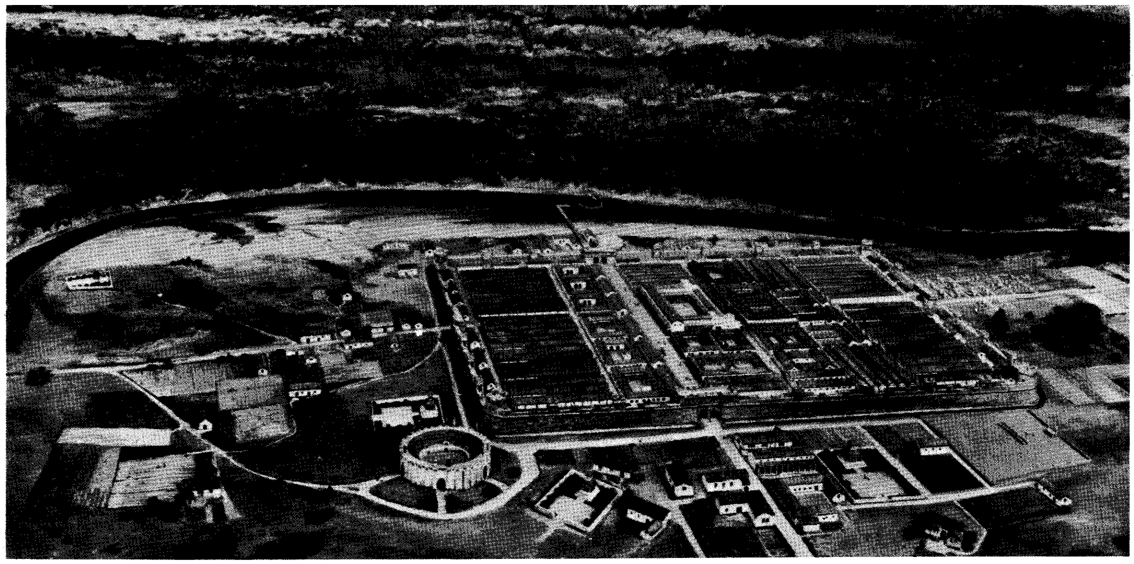
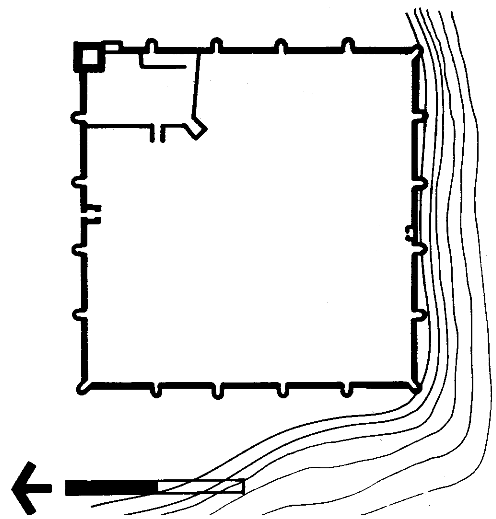


Fig 3.2.3.c Irregular Shape

3.3 Other interesting design of fortresses

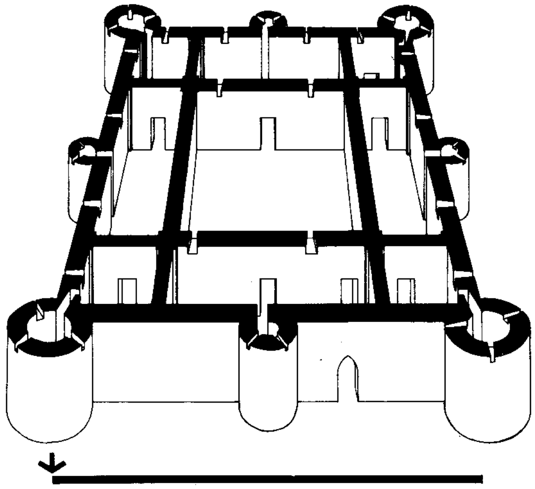


Model in the Grosvenor Museum of the Roman fortress at Chester



The Roman walls at Portchester ; plan

Fig 3.3.a The rectangular shape of the Roman walls of Portchester



Top and above
Castello Ursino at Catania in Sicily

Fig 3.3.b The rectangular shape together with some modifications gives the Castello dell'Imperatore at Prato some advantages. The sharp corner allowed better observation of the other corner and the protruding part of the castle.

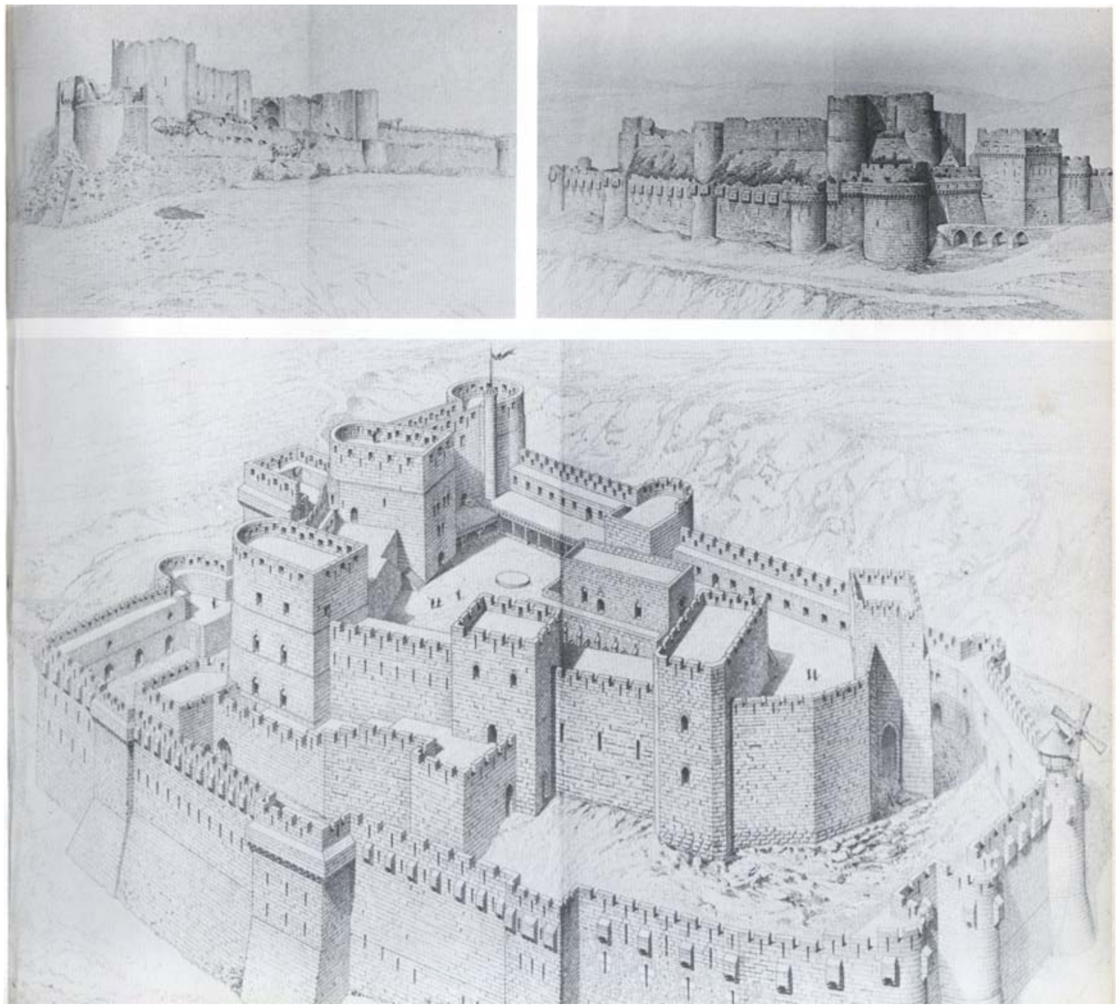


Fig 3.3.c

Top Left : Margat Castle from the south-east.

Top Right : View of Krak from the south-west.

Bottom: Le Krak des Chevaliers, an aerial reconstruction by Sauvageot

This structure was more complicated than others. Many walls were built with towers in many directions.

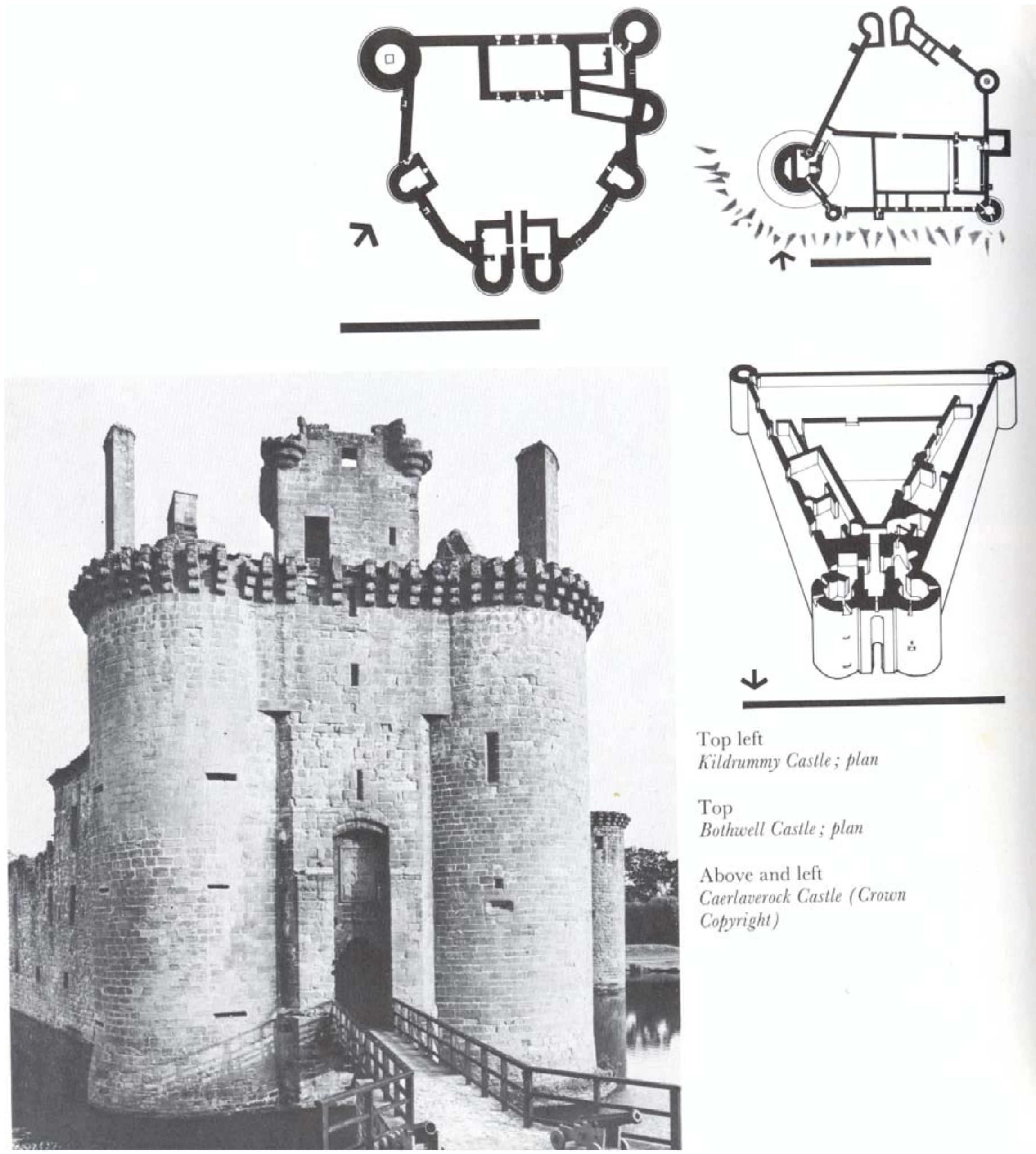


Fig 3.3.d The Caerlaverok Castle in Scotland from the thirteenth century. It links the Kildrummy Castle (top left) and the asymmetrical but pointed solution at Bothwell Castle (right-below) to form a perfect equilateral triangle with a powerful keep-gatehouse at one apex. Its chief disadvantage is the narrowness of the fighting area at the points of the triangle.

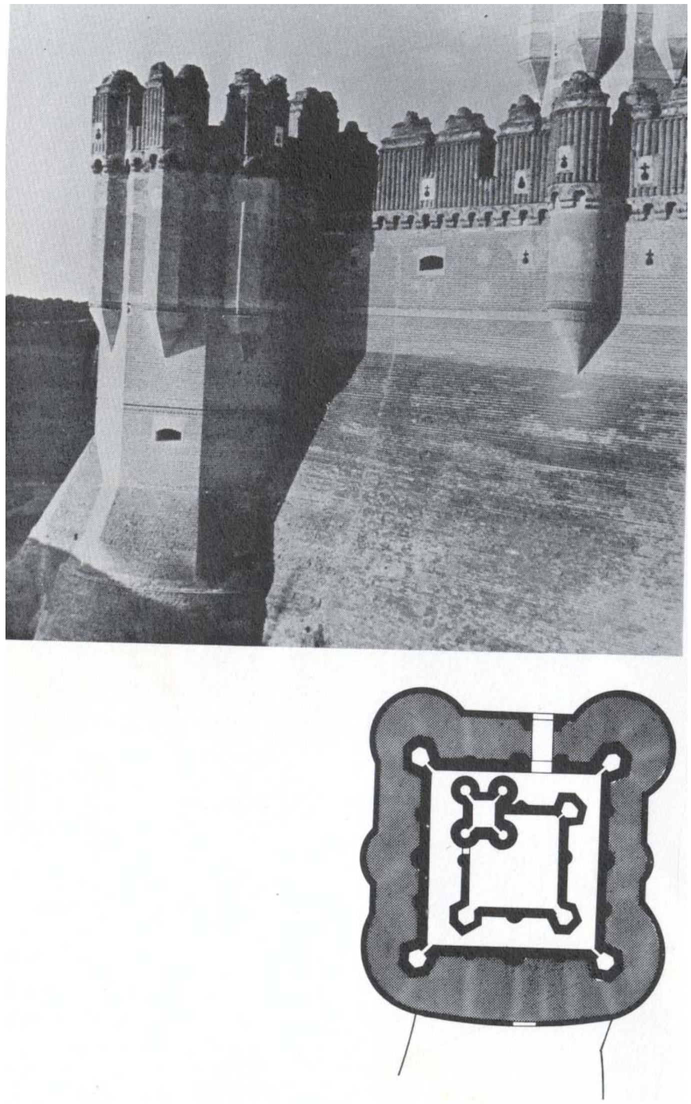


Fig 3.3.e The Coca, from Alberto Weissmiiller, has hexagonal corner towers which provides effectiveness in shooting but not efficiency in soldiers number. It needs quite a lot of soldiers just for one corner.

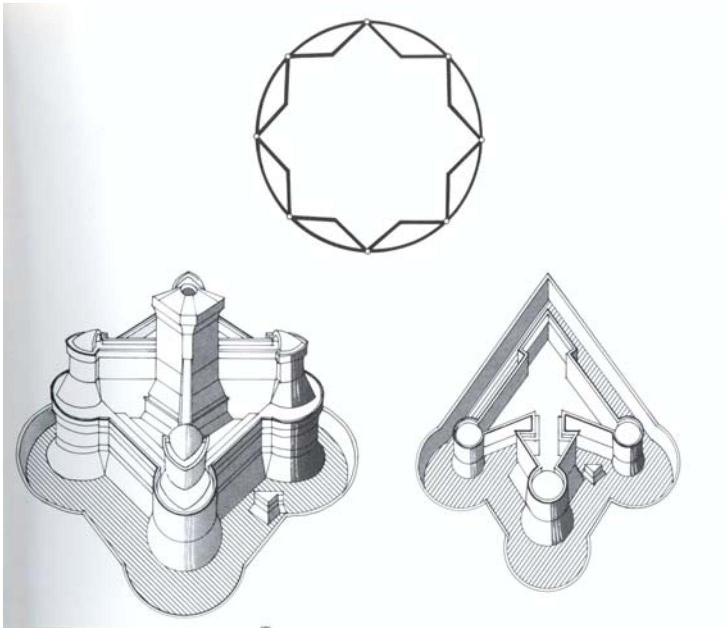


Fig 3.3.f Consider the fort on the bottom left. This fortification of Sforzinda has a strong central tower as a point of safety in the last retreat.

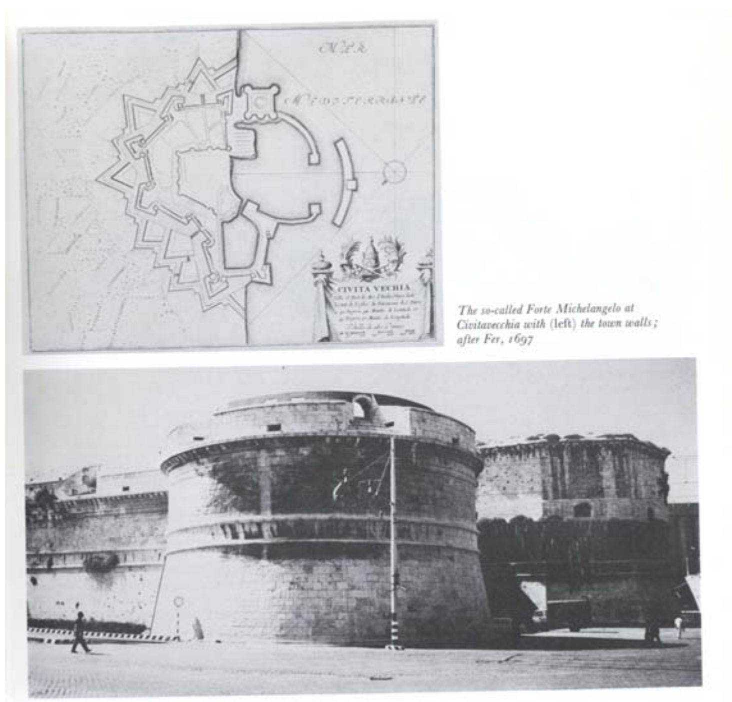


Fig 3.3.g Forte Michelangelo at Civitavecchia, it was designed by Michelangelo. This design was never used as a fort in war. It was only a symbol of power. Later came the design after Michelangelo as seen in Fig 3.3.h.

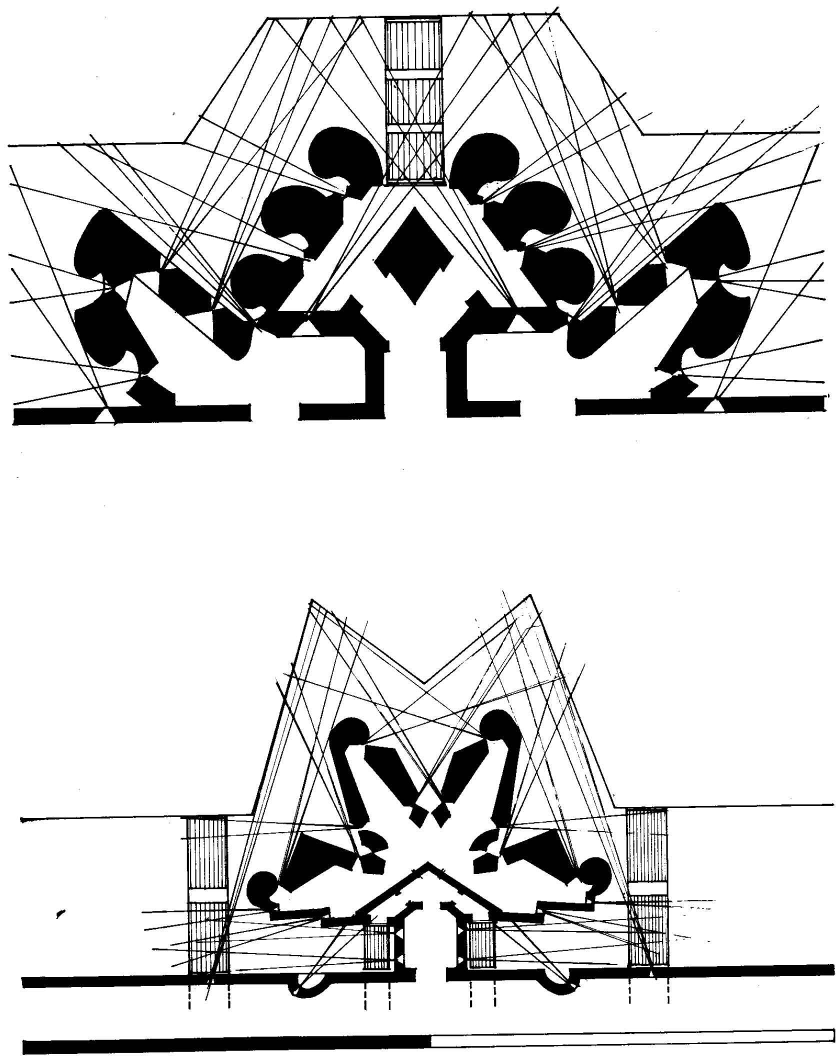


Fig 3.3.h Design after Michelangelo

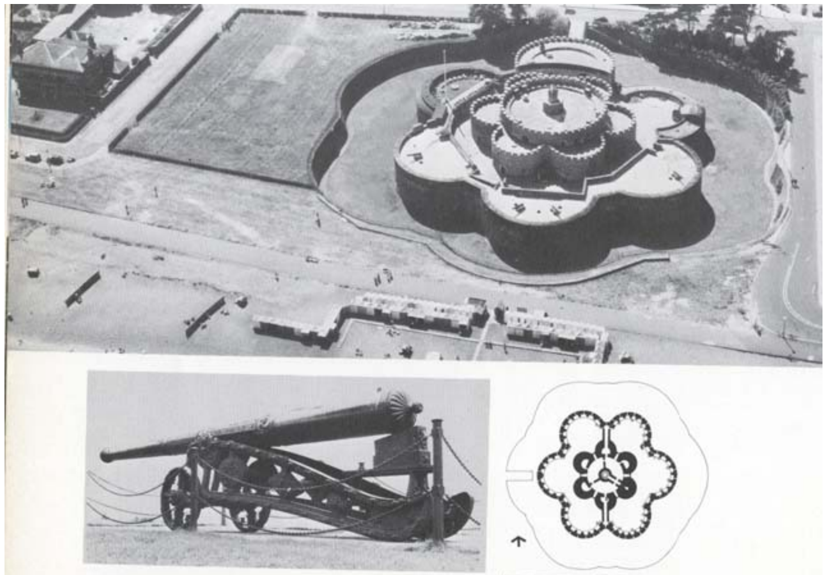


Fig 3.3.i This type of castle's main flaw is that the round-tip-end of the castle is vulnerable to attacks.

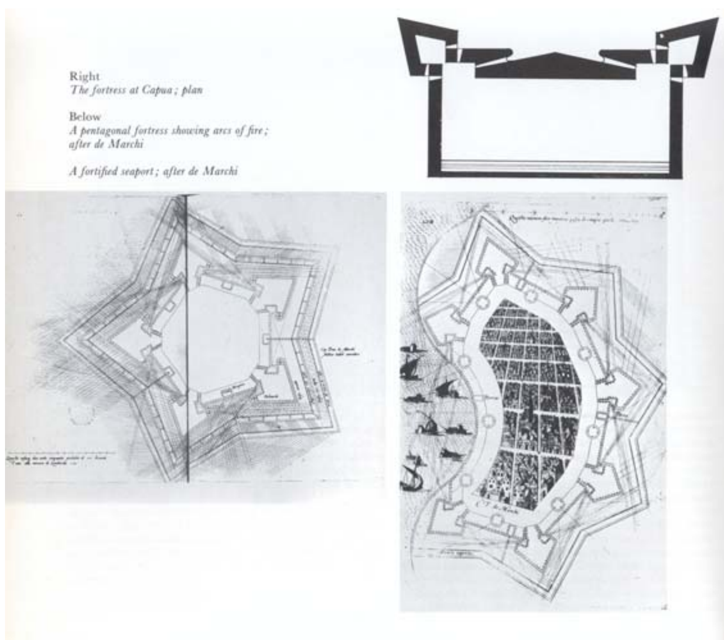


Fig 3.3.j A pentagonal fortress showing arcs of fire(left) and the fortified seaport (right)

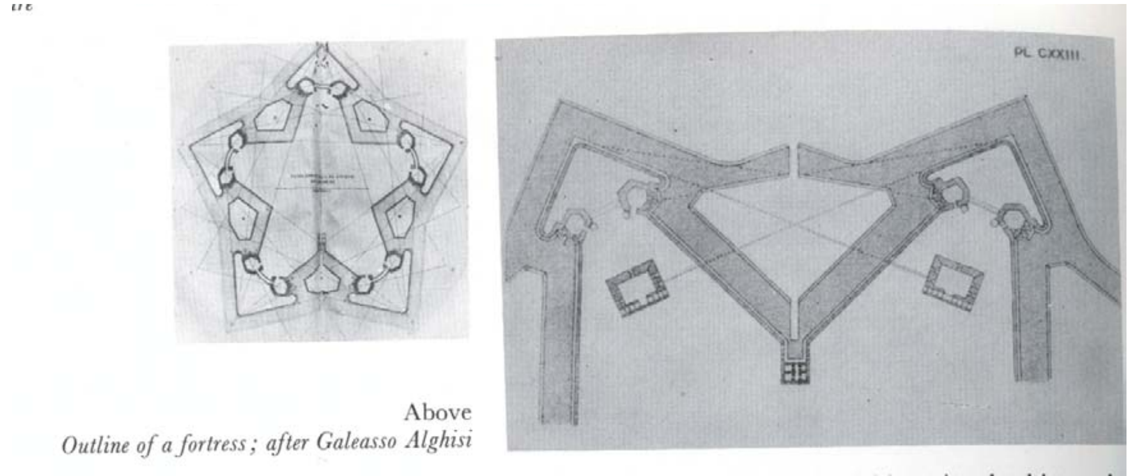


Fig 3.3.k A modified pentagonal fortress.

- ***Below are the designs of the fortification of a city.***

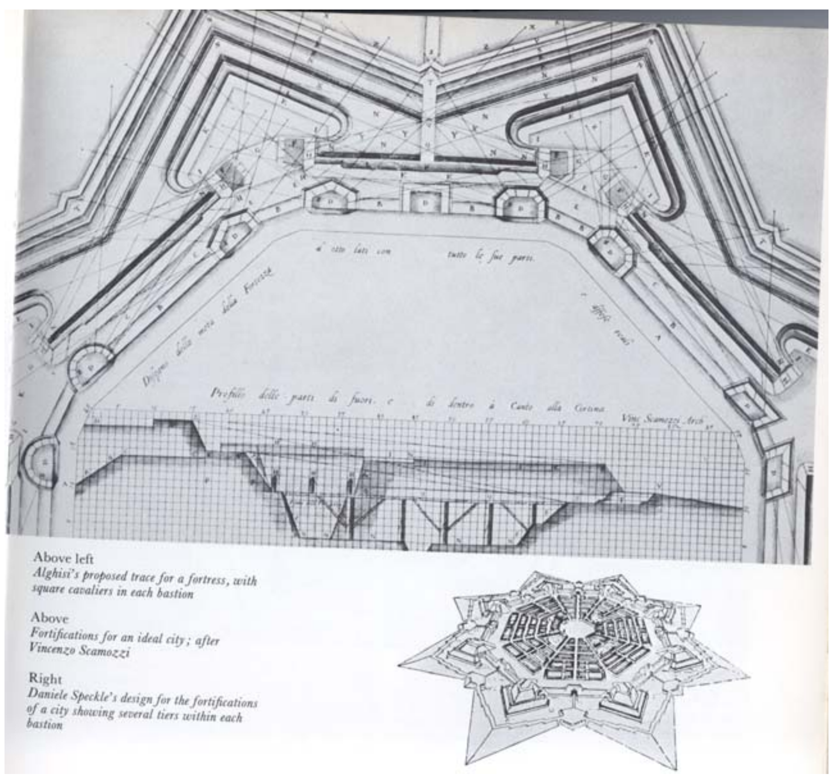


Fig 3.3.1

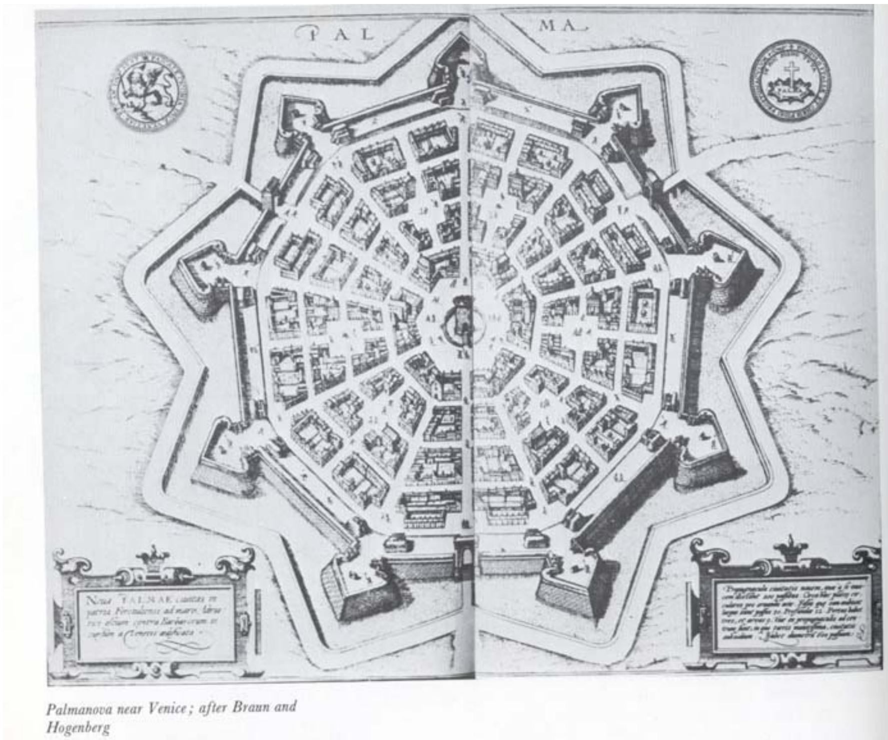


Fig 3.3.m

3.4 Another interesting field of study

- **The Great Wall**

Fig 3.4.a The Great Wall Of China

Construction of the Great Wall started in the 7th century B.C. The vassal states under the Chou Dynasty in the northern pasts of the country each built their own walls for defence purposes. After the state of Chin unified China in 221 B.C., it joined the walls in order to hold off the invaders from the Tsongnoo tribes in the north and extended them to more than 10,000 li or 5,000 kilometers.

A major renovation started with the founding of the Ming Dynasty in 1368. The renovation took 200 years to complete. The wall we see today is almost exactly the result of this effort. With a total length of over 6,000 kilometers, it extends to Jiayu Pass in Gansu Province in the west and to the mouth of the Yalu River in Liaoning Province in the east. Being 7.8 meters high and 5.8 meters wide at the top on the average, it has battle forts at important points, including the corners.

One of the best sections of the Great Wall is the Mutianyu. The Mutianyu section is crenellated for watching and shooting at the invading enemy. Some of the battle forts on the wall are as close as 50 meters apart.

In 1998, archeologists found that the Great Wall of China is 500 kilometers longer than the earlier recorded length. It was extended to Xinjiang and is now 7200 kilometres long. This extended part consists of the city wall and beacon towers, forming a complete defense system. The wall is identical to the sections at Jiayu Pass and Yumen Pass in terms of architectural style and function. The walls were made of yellow sandy stone and jarrah branches found locally. It is a man-made wall built for the purpose of defense as it can be seen by a large number of arrowheads found nearby.

The portion of the Great Wall in eastern China was made of brick while other parts of the wall in western China were made of yellow sandy soil and jarrah branches.

Fig 3.4.b Battle forts built on the summits of hills

Fig 3.4.c The Mutianyu section of the Great Wall

4.0 Troops Formations

In this section, we will see many different kinds of troops formations mainly in the ancient Roman and Greek armies.

Typically, formations that spread the men out in a wide, shallow arrangement, such as lines and crescents, are best for defending. These formations cover a wide area and prevent the enemy from getting through. In the case of spearmen, a line or crescent formation also allows individual soldiers to work together and support each other.

Formations which take wedge or arrowhead shapes tend to be much better for attacking than defending. It works just like an actual wedge - a pointed object is much better for penetrating a surface than a blunt object, because it tends to spread that surface apart. Thus, the men in a wedge formation will tend to push the enemy apart and break them up, and the enemy loses the advantage of their defensive formations.

Certain formations are more mobile than others. Soldiers can turn and re-position faster without breaking apart. This is important. Any division could be as mobile as any other if all the soldiers break formation and just run from one spot to the next. Of course, this means they are very vulnerable while they are traveling, so instead, a division will try to hold formation as it moves. Because of this, it may not be as agile as it otherwise could be.

4.1 Troops formations in the ancient Roman Army

The Roman army was divided equally into 4 quarters. Each quarter was called a **legion**, and was usually made up of 4200 men divided into companies known as **cohorts**. A cohort usually consists of 600 men. In desperate situations, the size of the legion could swell to 5000 men. Each legion was designed to be a team that had its own commanders. Tightly organized and well trained, the Roman legion had a simplicity that concealed its innovation and true power.

A **century** is a group of a hundred men within a legion. A man's wealth decided which century he should fight in. The rich usually served as the **cavalry**. A **maniple** is a group of two centuries.

In battle, the companies were arranged into three lines with spaces between each company. The first line is the **hastatii** which consisted of young men, still to prove themselves, equipped with javelins and spears. The second line of **principes** was made up of older men with superior weapons and cylindrical shields. In the third line were the **triarii**, veterans of proved courage. The actual fighting rarely reached the triarii, but if it did, it was a sign that the battle was not going well for the Romans.

A standard arrangement was to have three cohorts in the first two lines, two in the last and two in reserve, but any number of variations was possible. This arrangement allowed for a high degree of flexibility and maneuverability during battle. Thus, the Roman army was better able to re-deploy during battle to take account of new developments.

Each legion had a permanent standard to represent it in the form of an eagle. The legion's eagle was given religious worship, kept in a shrine and a man was assigned to carry it into battle. Loss of the eagle was considered a major disgrace.

- ***Formations of the Legion***

The foundation of Roman infantry tactics was based on the idea that by keeping troops in order, one could fight more effectively. Most military commanders of the day simply had their troops rush wildly at the enemy, relying on superior numbers, better soldiers, or luck to carry the day. The Romans realized that they could not always rely on these factors, so they turned to strategy. Each situation was handled differently, taking into account terrain, the type and strength of the opponent's troops and the type and strength of the Roman's troops.

Typical Legion Formation

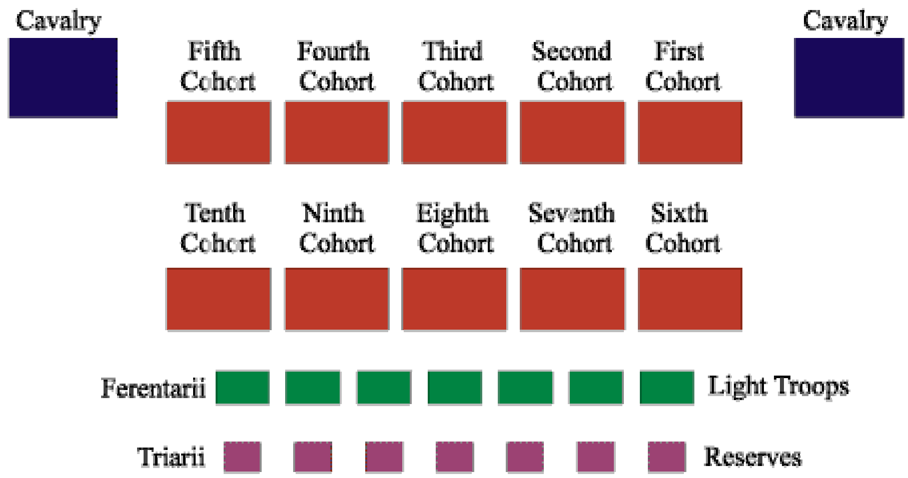


Fig 4.1.a Typical Troops Formation

This was the default arrangement for a full legion in battle. The cavalry rode up front, on the sides where they could protect the flanks. In between them were two rows of five cohorts. The rightmost cohort consisted of about 1100 infantry and 30 mounted troops, while the others contained about 550 infantry and 65 cavalry. Behind the main group were seven units of light troops, followed by seven units of reserves. All cohorts in each row were separated by medium-sized intervals, and the second row of cohorts blocked the intervals between those of the first row. The legions stood side by side, with intervals of perhaps one hundred and twenty feet, and formed the center of the battle line. The three maniples of the cohort stood side by side at intervals of about twelve feet, and in each maniple the second century was some eight or nine feet behind the first.

- ***Marching Formation***

When the legions were moving, a very different arrangement was required. The main part of the cavalry rode up front as a vanguard, followed by the infantry, in a long column of cohorts. Behind them were the army's baggage, servants, and vehicles, guarded by several units of cavalry. At the end were the best units of both infantry and cavalry to defend against attacks from the rear. The lighter units were arranged around the edges to act as scouts.

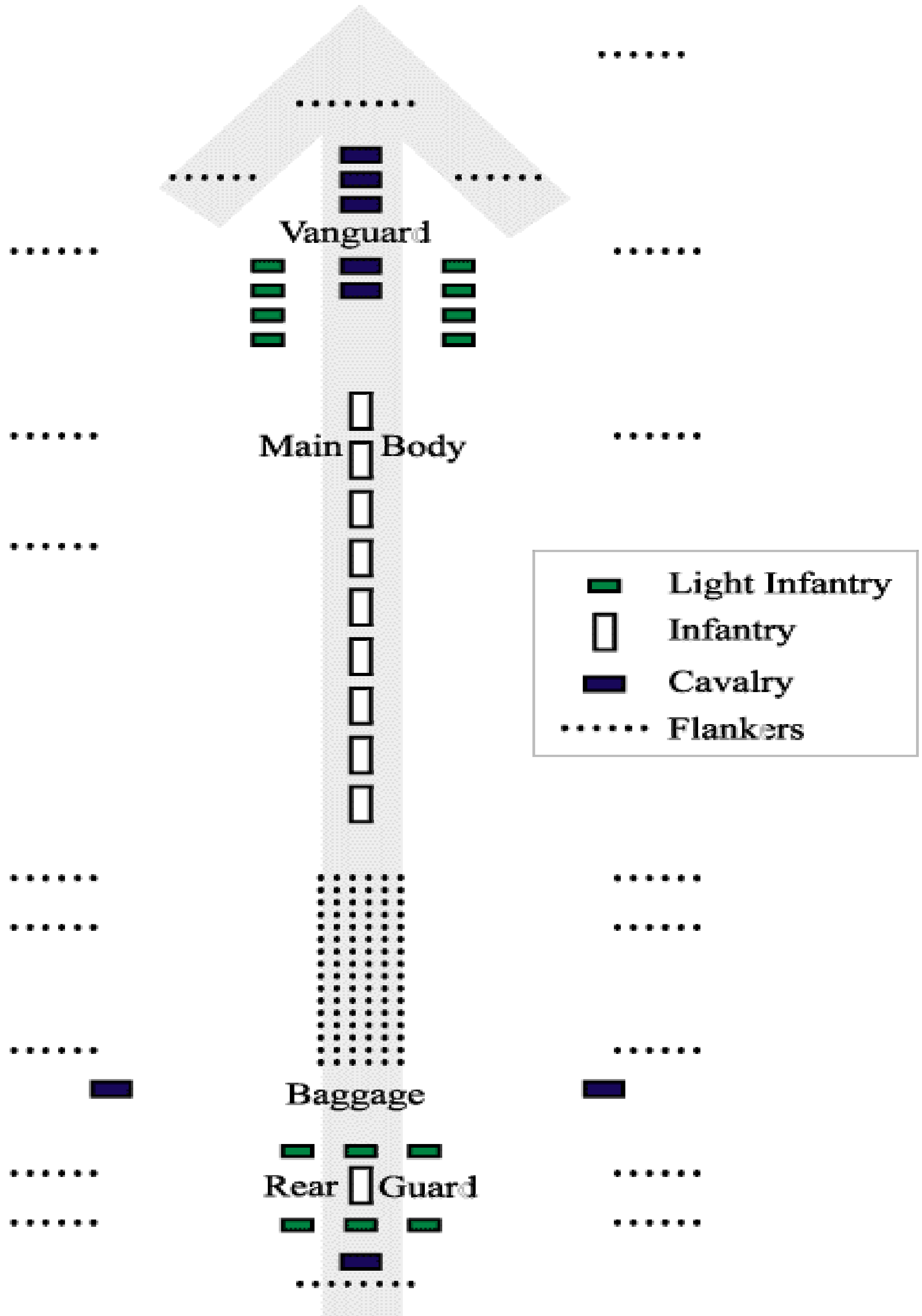


Fig 4.1.b Marching Formation

- ***Approach Formation***

When the legions neared the enemy, an "approach formation" was taken up in which the packs and saga were laid aside, shield coverings removed, helmets and crests put on. Sometimes this formation was started seven or eight miles away and might take two or three hours. This arrangement was generally in a line of three parallel cohort columns, each cohort in column of maniples with the centuries abreast or in column.

In the first case (centuries abreast), each legion was placed directly in rear of the previous one so that the whole army marched in a line of three parallel columns of maniples and could easily be faced to the right or left. Terrain permitting, the second case (centuries in column) was used, and all legions were placed abreast. Thus an army of four legions marched in twelve parallel columns of centuries.

1. The First Formation

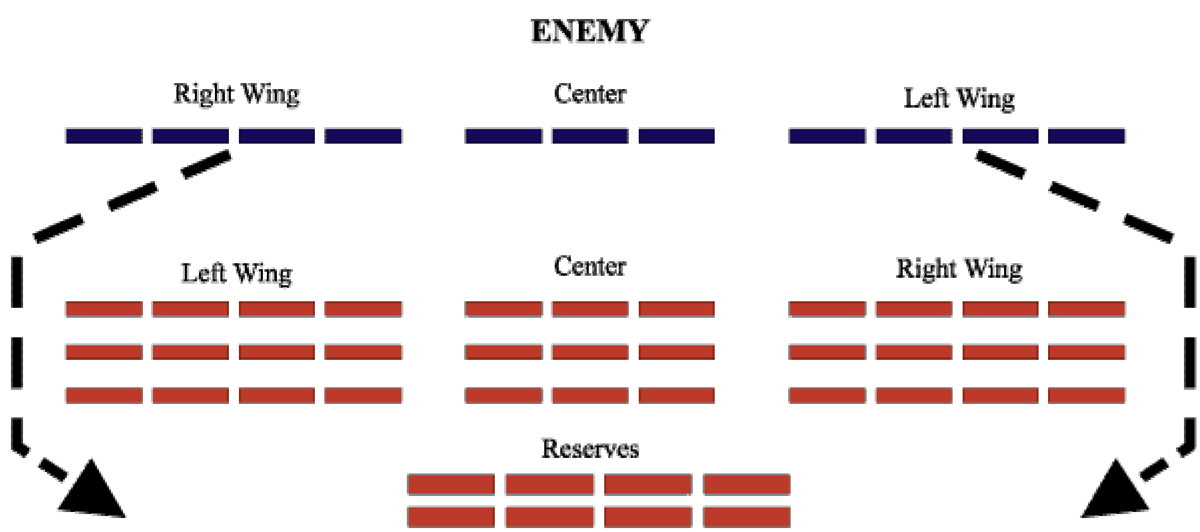


Fig 4.1.c The First Formation

This tactic, designed for level terrain, assumes that the wings are more powerful. If the enemies made their way around the flanks, the reserves will be able to counter.

2. The Second Formation

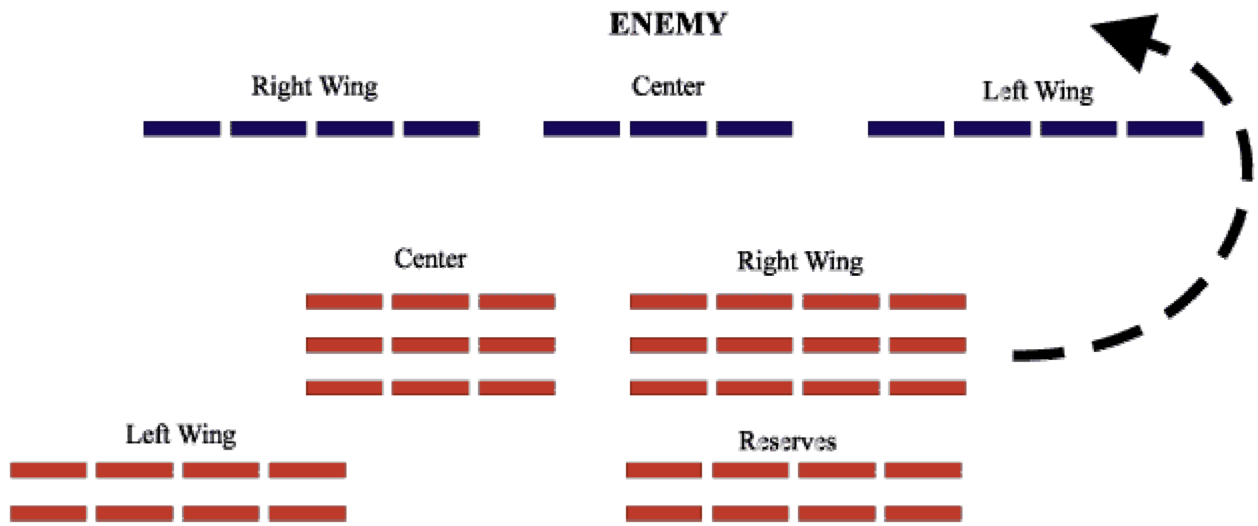


Fig 4.1.d The Second Formation

Some considered this formation to be the best. The left side of a soldier and hence the left side of the army was considered to be weak as the soldiers had to support the weight of the shield. The right wing moved around the opponent's left and attacked from the back. The left wing maintained its distance. The reserves either support the left wing or guard against the enemy attacking the center.

3. The Third Formation

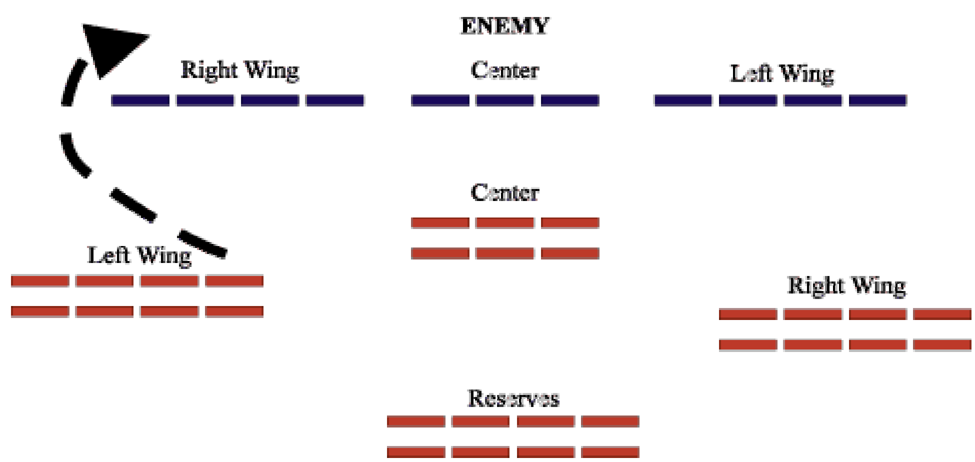


Fig 4.1.e The Third Formation

This formation is the opposite of the second one. It is used when the left wing is stronger than the right. In this case, the left wing attacked the enemy's right wing.

4. The Fourth Formation

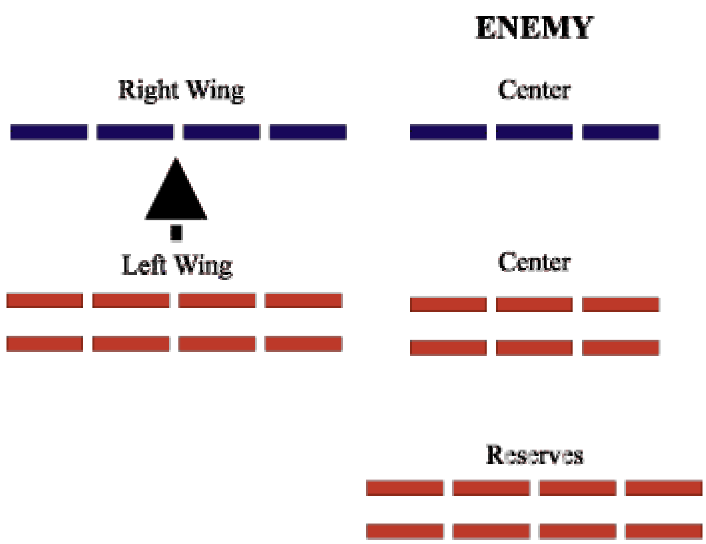


Fig 4.1.f The Fourth Formation

In this formation, the entire army is brought close to the enemy. Then, both the right and left wings will charged at the enemy. This would often surprise the opponent, allowing for a quick resolution. However, the army will be separated into three groups during the process. Therefore, if the enemy survived the attack, the center of the Roman Army will be vulnerable to attacks.

5. The Fifth Formation

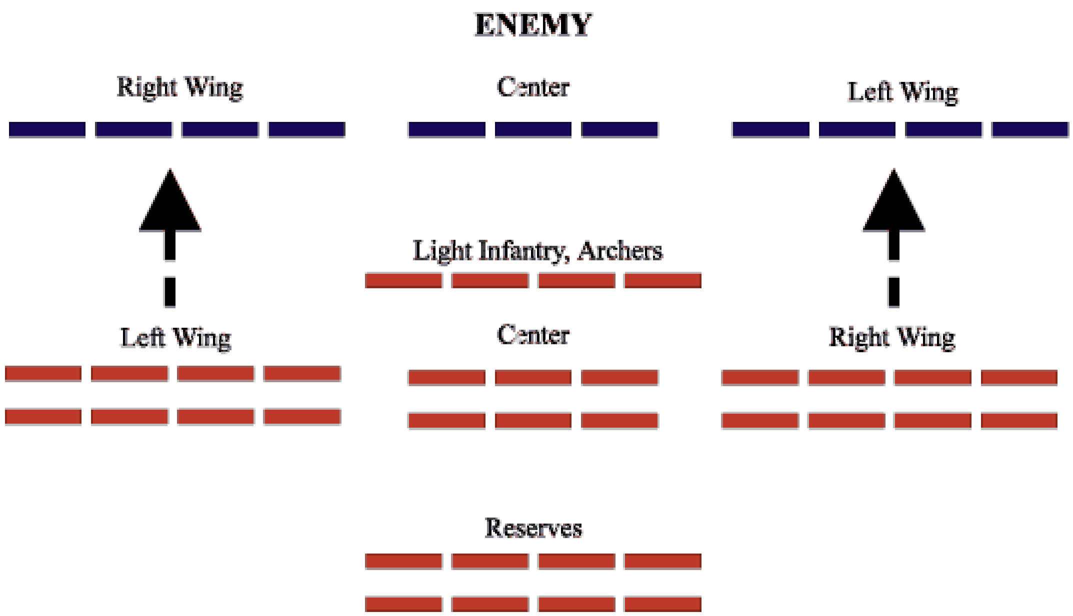


Fig 4.1.g The Fifth Formation

This formation is about the same as the fourth formation except that now, light infantry and archers were positioned in front of the center, making it less vulnerable.

6. The Sixth Formation

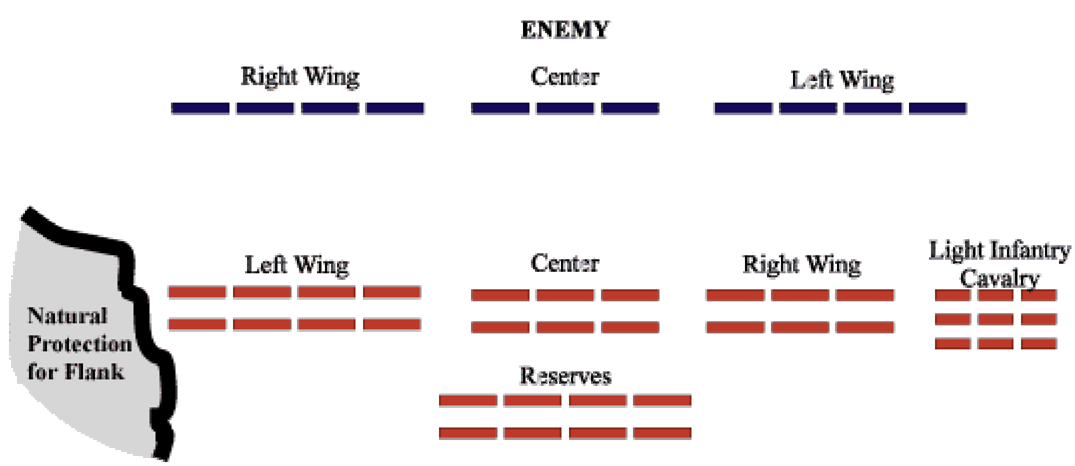


Fig 4.1.h The Sixth Formation

When the Romans were outnumbered or had inferior troops, this was often the only hope for victory. The left flank was kept guarded by a city, the sea, a river or some other protection of that kind. The right flank was protected by the light troops and cavalry. In this way, both sides will be well covered.

- ***The "Turtle Shell" Formation***

The "turtle shell" might be formed in many cases. Some examples are when the battle is being fought uphill, when the army is storming a walled town or fortified camp or in any case where troops were exposed to a plunging fire, The front-rank men will closed in and held their shields in front, the flank men will hold theirs on the sides and the others will raise theirs overhead like overlapping shingles on a roof. This formation gave almost complete protection.

4.2 Troops Formations in the ancient Greek Army

- ***The Phalanx***

In ancient Greek warfare, the Phalanx is the main troops formation.

Prior to the evolution of the phalanx during the seventh-century BC, war was fought by very limited forces derived exclusively from the social infrastructure of Greek city-states. The integration of the phalanx into tactical warfare became a military revolutionary idea as well as a social evolution.

The Phalanx is a dense formation of pike equipped troops. The formation is very strong at the front but rather vulnerable to flank attacks. From the front, the formation looked like a hedgehog. The phalanx was composed of a compact unit of hoplites (a term used for the Phalanx's soldiers), often longer in length than in width. The phalanx was not a permanent formation. Its dimensions and approach to attack depended on the general's tactics and the size of the army.

The Phalanx formation called for each man to trust his neighbouring infantryman, often a friend or relative. With a shield in his left hand and a spear in his right, each man depended on his fellow hoplite's shield for full body coverage. Battles were won and lost depending on the phalanx's ability to hold its formation.

The Phalanx had to meet its enemy with enough momentum to move forward, but it also had to maintain order within the ranks so as not to leave gaps between columns. A gap in the chain of infantrymen could be fatal if exploited. As a result, the best troops were placed at the front and back of the Phalanx.

The phalanx continued its tactical supremacy for many centuries. Later, it was rendered obsolete by the professional and perfectionist soldiers in the Roman legions.

- ***The Square Formation***

The old notion of fighting in large square battle formations, which remained relatively unchanged since ancient Greek times, was shown to be outdated and inefficient by Gustavus Adolphus's brilliant strategy during the war. The large squares, also known as tercios, were used because a lot of troops can be concentrated in one large area.

This was not a very efficient way of using available manpower. One of the biggest drawbacks of the tercios was that it relied on the troops at the front to do most of the actual fighting while those in the middle and back were left out. In addition, because of its large size it was difficult to maneuver. Adolphus organized his troops in linear formation of 6 soldiers wide. This allowed all the soldiers to be involved in actual fighting and made the formations much easier to maneuver.

4.3 Other Military Formations

- ***The Column Formation***

Definition: A formation in which elements are placed one behind the other.

Advantage: This formation helps to conceal the number of units in a convoy. The enemy can look at the tracks left by a squad to estimate how many units it is up against. Take 12 trucks for example, the trucks may travel in columns of 4 or 6. Thus, there will only be 2 or 3 columns. As a result, the enemy may have a hard time tracking the number of units.

Disadvantage: It leaves the entire convoy vulnerable to aircraft or mortar fire. For example, an assault on the convoy can concentrate their attack down the center of the column and inflict damage to every unit.

- ***The Wedge Formation***

Definition: A formation in which elements are placed to each side of a central unit, extending outward and behind the central unit itself.

Advantages: The wedge formation is good for approaching a battle and offers defense to the convoy, aiding in the prevention of being flanked to either side. It is best used by infantry or armored units when traveling between mountains or within wooded areas, where the threat of being ambushed or flanked is higher.

Disadvantages: It lacks in the firepower concentration on specific targets and this formation cannot conceal the number of units in the convoy.

- ***The Snake Formation***

The snake formation is a flexible attack layout, designed for maximum mobility on the battlefield. An army in snake formation can change directions easily and tends to focus a large number of divisions in a small area.

Fig 4.3.a Snake Formation

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